User Manual

Issue 1.05

Applies to: microK 100 and microK 200

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Firmware version 1.16+

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1 Introduction

The microK 100 and microK 200 thermometry bridges use a completely new ADC (analogue-to-digital converter) and low noise amplifier technology (see section 7: “The microK Technology”) to provide levels of performance previously only available using AC resistance bridges. Uniquely, the microK bridges also work with thermocouples and thermistors so that they can be used to calibrate precision, noble metal thermocouples (type R, S and the new gold-platinum thermocouple) as well as simply monitoring the temperature of standards and liquid baths in your laboratory. With three measurement channels (expandable to 92 channels) and the ability to measure all the temperature sensors you are likely to use in your laboratory, the microK should be the only thermometry instrument you need in your calibration laboratory or measurement system. They are also the first instruments of their type to be completely solid-state, making them highly reliable.

Despite their sophistication, these instruments are very easy to use. There are no knobs and dials, just a colour touch screen that makes use of the familiar Windows CE™ operating system. If you use a Windows™ operating system on your PC, you will find these instruments intuitive and easy to use. The USB port on the front panel allows you to plug in and use other devices that work with Windows CE™ such as a mouse, keyboard or flash drive.

Readings can be displayed in resistance ratio, ohms, volts or temperature units (°C, °F or K). Algorithms for conversion to temperature include:

PRTs:	ITS-90
	Callendar-Van Dusen: IEC751 (ASTM E1137) or custom coefficients
Thermocouples:	IEC584-1 (ASTM E230 & E1751) for type B, E, J, K, N, R, S, T
	Type L polynomial
	Gold Platinum Reference Function Polynomial
Thermistor:	Steinhart-Hart

This manual provides a comprehensive guide to using the instrument. We recognise that you will probably not wish to read it through at this time so suggest you read the safety section below, take one of the tutorials in section 2 and then refer back to the manual using the list of contents to find additional information as required.

1.1 Unpacking

Your microK product should comprise the following items:

- microK precision thermometer
- power lead suitable for your country
- this user manual

If any item is missing or damaged, please report this immediately to your supplier. If possible, we recommend that you retain the packaging material in case you need to return the instrument for calibration or service since it has been designed to ensure that your microK is properly protected during transportation.

1.2 Safety

The microK is a precision instrument, designed for use in a laboratory. It complies with the requirements of safety standard EN61010-1 (2001) and is therefore safe to use in laboratory or light industrial environments. It is not intended for use outdoors or in extreme environments (refer to specification in Section 12).

The microK is likely to be connected to thermometer sensors in use and the operator should take care to ensure that the complete system is safe. For example, metal sheathed thermometers may be connected to the microK and then placed in a furnace powered from a 230V electrical supply. Single fault conditions in such a furnace could lead to the thermometer wires and the front terminals of the microK to which they are connected becoming electrically live and therefore a hazard to the operator. Suitable precautions should be taken, such as using an isolating transformer in the supply to such a furnace. If you require further advice on safety issues, please contact Isothermal Technology or one of

our appointed distributors - we have extensive experience of thermometry and can provide advice and equipment to help you.

Retain these instructions. Use only as specified in these operating instructions or the intrinsic protection may be impaired.

Please observe the following safety precautions:

- Do not use your microK if it is damaged
- Only connect to an earthed supply socket. THIS UNIT IS CLASS 1 CONSTRUCTION AND MUST BE EARTHED!
- Connect only to a power supply with a voltage corresponding to that on the rating plate
- This equipment is for indoor use and will meet its performance figures within an ambient temperature range of 5°C to 40°C with maximum relative humidity of 80% for temperatures up to 31ºC decreasing linearly to 50% RH at 40ºC
- Equipment is for operation at installation category II (transient voltages) and pollution degree 2 in accordance with IEC 664 at altitudes up to 2000 metres
- Before replacing a fuse, DISCONNECT THE EQUIPMENT FROM THE ELECTRICAL SUPPLY
- The fuse is contained in the IEC socket on the rear panel. It must only be replaced with a fuse of the type and rating marked on the rear panel
- If a replacement fuse fails immediately, contact your local service agent. DO NOT replace with a higher value
- Always use the power cord supplied. Your sales outlet can provide a lead suitable for your country
- This equipment is for use in moderate climates only. NEVER use the equipment in damp or wet conditions
- Avoid excessive heat, humidity, dust & vibration
- Do not place liquid filled containers on the equipment
- Do not use where the equipment (or any associated accessories) may be subjected to dripping or splashing liquids
- Ensure that the power switch is easily accessible to allow the unit to be switched off
- The equipment weighs 13kg; use the handles provided. Always disconnect the equipment from the electrical supply and any ancillary units before moving
- Ensure that tabletop equipment is placed on a solid, level surface, which is able to support its weight (and that of any attached accessories)
- Ensure all cables and wires are routed safely to avoid tripping: also to avoid sharp bends and pinches
- Clean only with a damp cloth. Do not wet or allow moisture to penetrate the unit. Do not use solvents. See section 5.3 for details of cleaning procedure
- The product should be subjected to regular in-service inspections as required by local regulations; a yearly interval is suggested

- Verify that the supply cordset is undamaged and that the enclosure is bonded to protective earth. Do not apply earth test currents to any front panel terminal nor to the shrouds of the USB, RS232, GPIB or Ethernet connectors
- The product is designed to comply with EN 61010-1 and can be flash tested. It is fitted with radio frequency interference suppressors. Therefore it is recommended that only a D.C. test be performed. Performing flash tests repeatedly can damage insulation
- This equipment contains no user-serviceable parts. Refer all repairs to qualified service personnel. Contact Isothermal Technology or one of our appointed distributors for details of approved service outlets

1.3 Powering Up Your microK

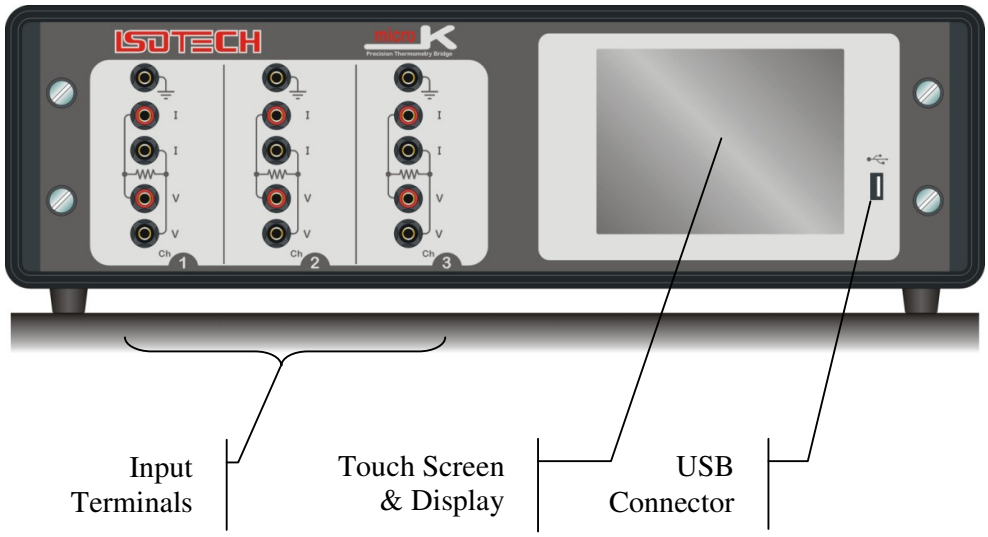
The microK operates on any standard AC electrical supply (88-264V RMS at 47-63Hz) so unless your supply is unusual you can simply use the power cord provided to connect your microK to a suitable electrical outlet.

The power switch is located at the rear of the instrument, immediately below the IEC connector. When you turn your microK on it will go through a standard Windows CE™ boot sequence and then display a Window containing the *Resume* button. Press *Resume* to restart the microK in the configuration it was in prior to the last power down, you will then see the Main Window and be ready to operate your instrument.

Before pressing the *Resume* button, make sure that any thermometers attached will not be damaged by the sense currents that will be applied (the last values used). If there is a problem, disconnect your sensors before proceeding and then reconnect them after changing the sense current to the required values.

1.4 A Quick Tour of Your microK

On the front panel of your microK you will find the input terminals for the three measurement channels, the touch screen/colour display and a USB connector:



Input Terminals: The input terminals accept 4mm plugs, spades or bare wires. The current (I) and voltage sense (V) terminals are spaced on ¾" centres so that standard BNC to 4mm adaptors (not supplied) can be used to connect to thermometer sensors that have BNC terminations.

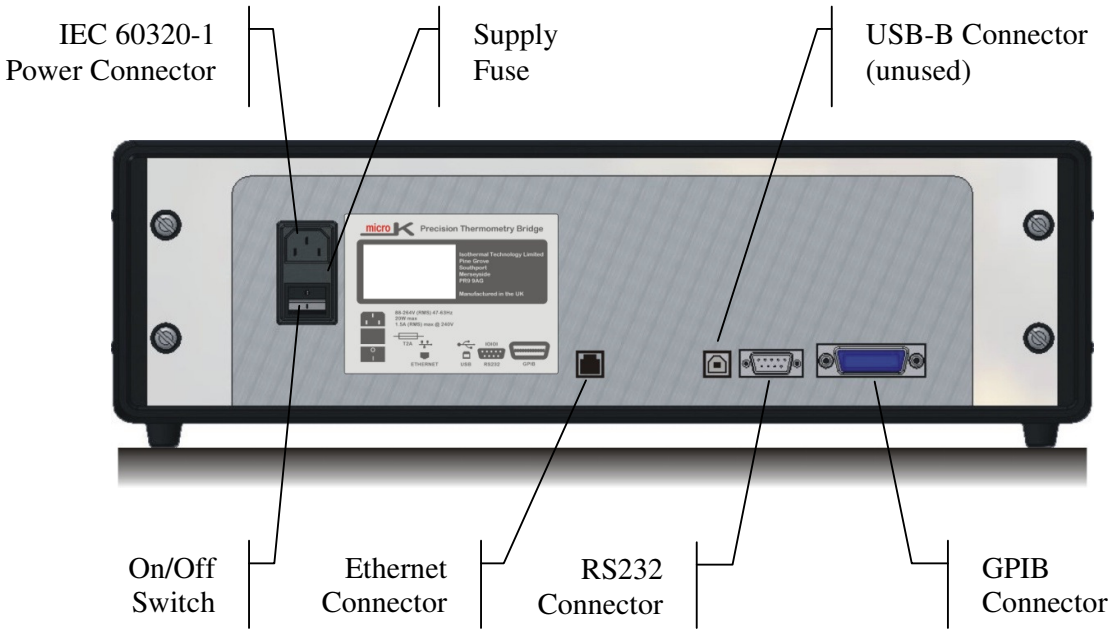
The contact material for the connectors is gold plated tellurium-copper, offering extremely low thermal EMFs when connected to copper wires/connectors. This is essential when using precision thermocouples.

Display: The display is a colour TFT VGA (640 x 480) LCD with a long-life CCFL (cold-cathode fluorescent lamp) backlight. A touch panel is mounted in front of the display so that you can control the instrument by simply touching the buttons displayed on the LCD. The touch panel is an industrial grade component offering good durability. It is intended to be operated with a finger. A stylus intended for PDAs may also be used – never use a sharp object with the touch panel as this may lead to premature failure.

The USB Connector: The USB connector is primarily intended to allow you to connect a USB flash drive, store measurement results and transfer these to a PC. The flash drive may also be used to backup the databases of thermometers, reference resistors and instrument configurations for your microK. Other USB devices such as a mouse, keyboard, keypad or USB hub may be connected to the

USB port and used, provided they utilise the standard class drivers provided with the Windows CE™ operating system incorporated in your microK.

On the rear panel of your microK you will find the electrical supply connector/power switch/fuse module plus the interface connectors that allow you to connect your instrument to a PC. The RS232 and GPIB ports allow you to control the instrument and take measurements from a PC with your own software (see sections 9 and 10). The command protocol employs the widely used SCPI format (see section 11 for details). The RJ45 Ethernet connector allows the microK to be connected to your network. The USB-B connector is used to load firmware during manufacture and should not be used during normal operation.



2 Making a Measurement (Tutorials)

The operator interface is powered by the Windows CE™ operating system. With the widespread use of Windows™ applications on PCs, driving your microK should be fairly intuitive. As with most Windows™ applications, it is possible to navigate your way through a process using a number of different paths, so rather than describe each window and the function of each button and then leaving you to work out how to operate the instrument, we provide you with a number of tutorials that illustrate common applications. Even if these do not describe your application, it is worth working through one of them since it will provide you with a broad understanding of the extensive features available on your microK.

A traditional description of the function of all the features provided by the operator interface is given in section 3.

2.1 Fixed-Point Calibration of an SPRT Using Zero-Power Extrapolation

Calibrating an SPRT using fixed point cells offers the lowest possible calibration uncertainty. The process involves measuring the resistance of an SPRT with respect to an external reference resistor whilst at a number of temperatures (by immersing it in a number of fixed point cells) and then using that information to generate calibration data for the thermometer. The reference resistor should be a DC or AC/DC resistance reference standard maintained at a constant temperature in an oil bath or similar resistor maintenance system.

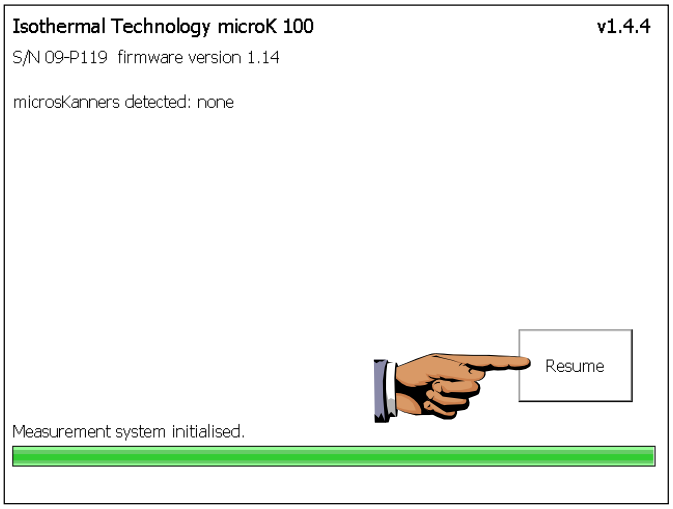
The sense current used to measure the resistance of a PRT (for example, the 1mA used with a 25Ω SPRT) causes a small but significant amount of self heating of the platinum element (generally a few mK). This offset is nominally constant under given conditions and is often ignored since it should affect the thermometer equally during calibration and in use. However, the offset can vary (even when conditions are apparently identical) due to differences in the thermal contact between the thermometer and its environment. This means that the same thermometer may exhibit a slightly different resistance when used in two

identical temperature sources or even in the same temperature source after being removed and replaced. This effect is significant in the most accurate thermometry work.

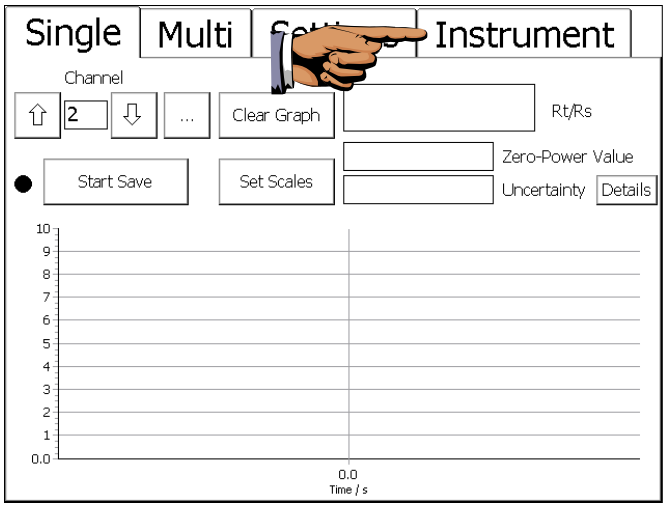
This uncertainty can be eliminated by determining the resistance of the SPRT at zero current (zero power). Whilst the resistance cannot be measured with zero current, it is possible to measure the resistance at 2 different currents and extrapolate back to determine the value at zero current. Historically, the most common way to do this was to make a measurement at the normal current and then to increase (or decrease) the current by a factor of $\sqrt{2}$ ($\approx$1.414). This changes the power by a factor of 2 and allows easy determination of the zero-power resistance (by subtracting the change in resistance from the first measurement). In fact a better method is to make a measurement at 2 currents that are in the ratio 0.56:1 (see section 6.1) and then extrapolate back to the zero power value. The microK is unique in being able to sequence the current and generate a zero-power corrected value (including an uncertainty figure) without using any external software.

This tutorial describes how to make a zero-power corrected resistance measurement of an SPRT against an external reference resistor at a single temperature and logging all this information to files on a USB flash drive:

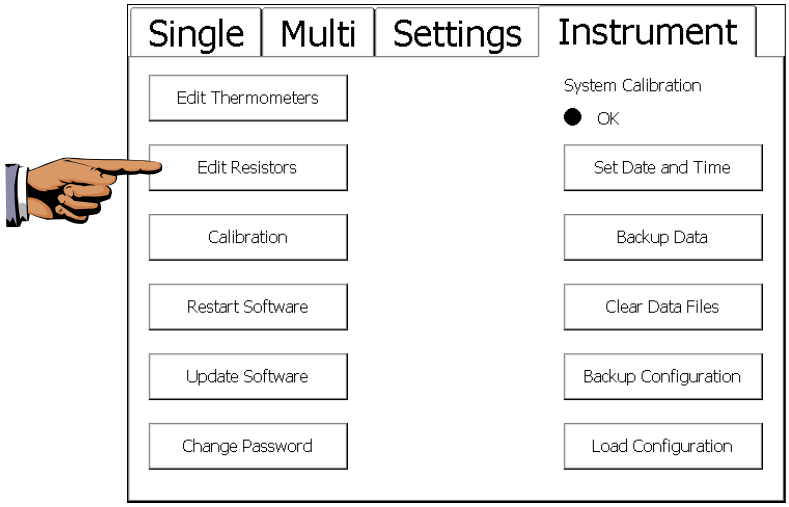
From start-up, press *Resume* to restart your microK:



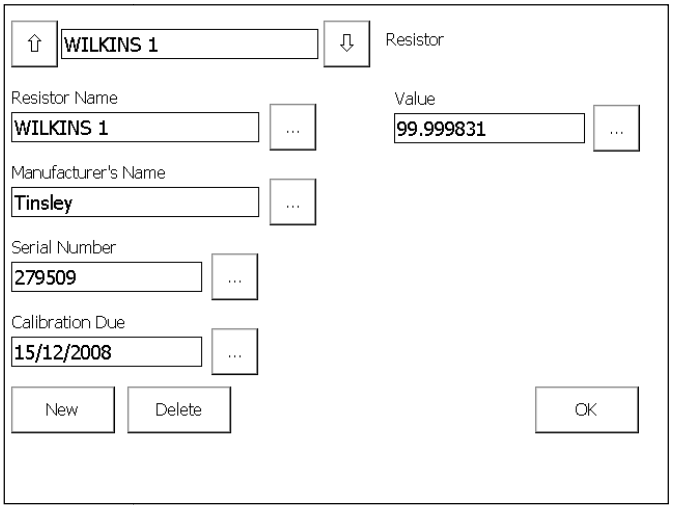
Before making any measurement, you will have to enter information about the reference resistor into the microK's database. When the main window opens, press the *Instrument* tab:



In the *Instrument* tab, press *Edit Resistors*:



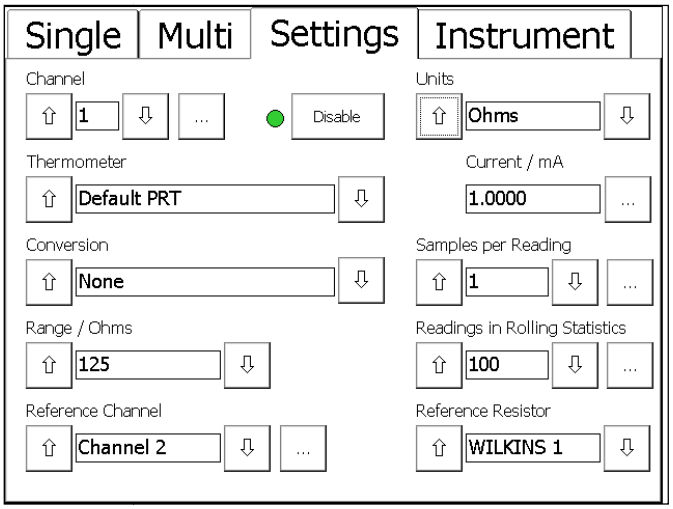
You will be prompted to enter the password (set to "1234" initially, but this should be changed before using the microK in a real measurement/calibration application to ensure security – see section 3.7.5.2). Enter the password to open the resistor database window. Press *New* to create a new resistor entry in the database and enter data by pressing the ellipses button by each field:



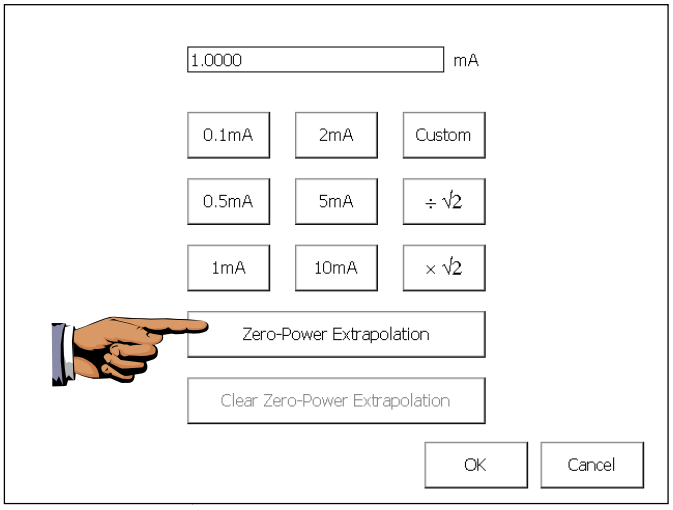
Press *OK* to close the resistor window.

Connect the SPRT to be calibrated to channel 1 (see section 4.2 for details on how to connect 4-wire PRTs) and the reference resistor to channel 2.

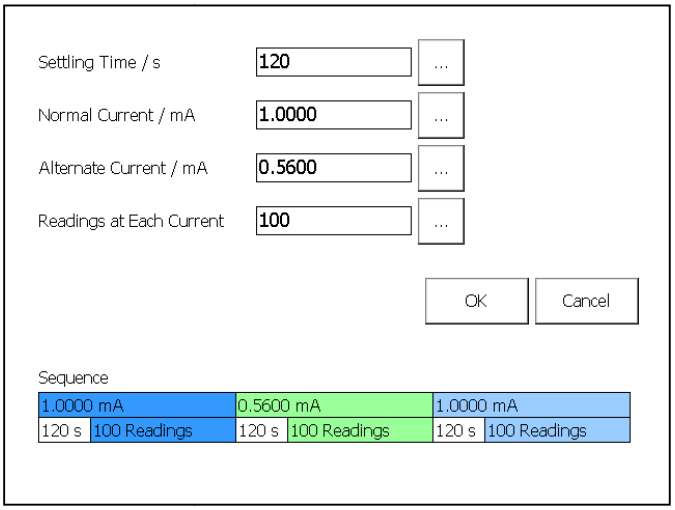
Press the *Settings* tab in the main window and disable channels 2 and 3 (this will speed up measurements on channel 1, which we will be using) by using the up/down buttons by the *Channel* box to select these channels and pressing *Disable*. Use the up/down buttons to return to channel 1. Use the up/down buttons by each box to select the required settings for the SPRT:



Press the ellipses button by the *Current mA* box to open the 'Current' window:



Press the *Zero-Power Extrapolation* button to open the current sequence window:



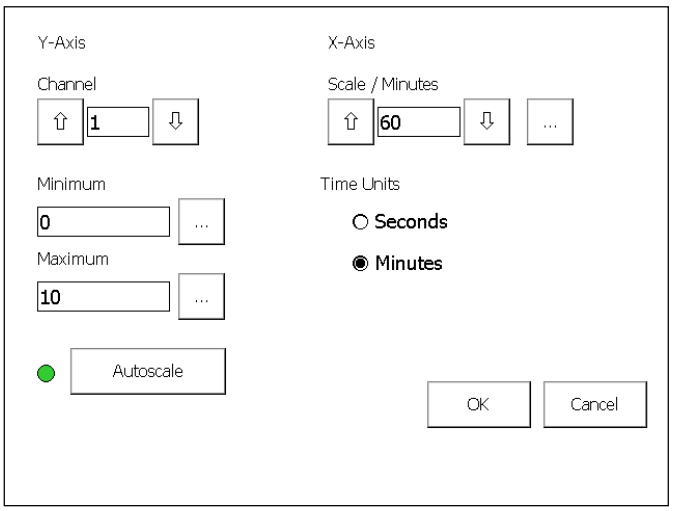
This window allows you to define the measurement sequence used to calculate the zero-power resistance. The measurement sequence comprises a measurement at the normal current followed by a measurement at the alternate current and then a final measurement at the original (normal) current. Before each measurement, the microK waits for the defined settling time in order for the thermometer to come to thermal equilibrium following the change in current.

If the settling time for the thermometer is not known, it can easily be determined by measuring its resistance at the (fixed) normal current and then manually

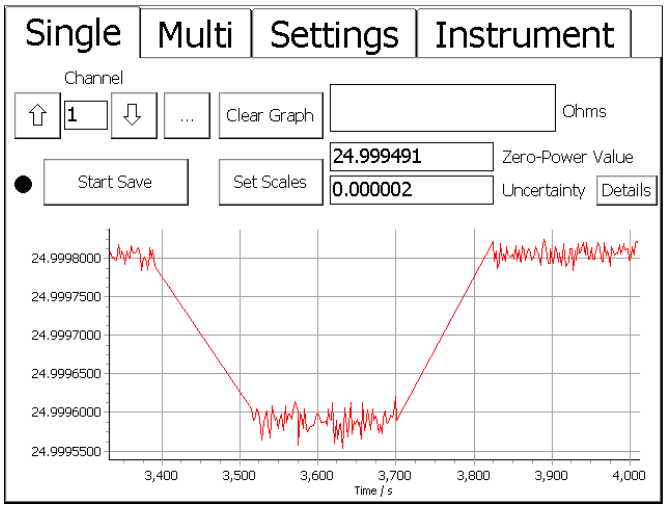
changing this to the alternate current whilst monitoring the results in the ‘Single’ tab (which will show the settling characteristics of the thermometer graphically).

Press *OK* to close the ‘Current Sequence’ and ‘Current’ windows and return to the main window.

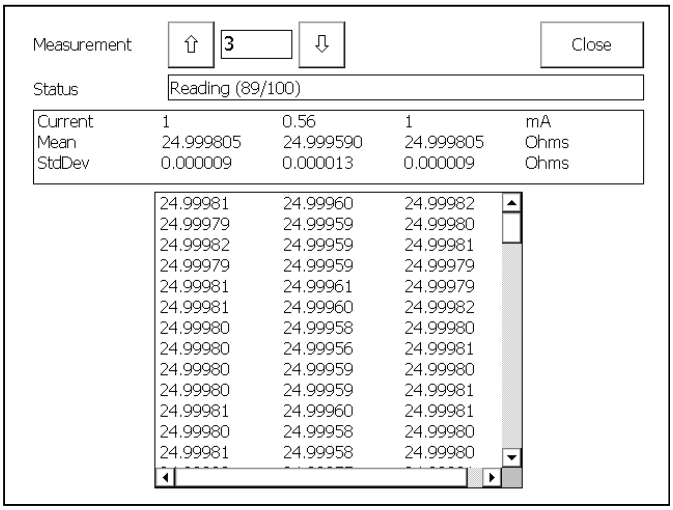
Press the *Single* tab to see the measurements in numeric and graphical form. Set the graph scales by pressing *Set Scales*. This opens the graph scales window. Ensure that autoscaling is turned on (press *Autoscale* to toggle autoscaling on/off, the status of autoscaling is shown by the adjacent indicator). Use the radio and up/down (or ellipses) buttons to set the x-axis to 60 minutes:



Press *OK* to return to the main window. The measurement system will now accumulate data and after 60 minutes the graph will begin to scroll to show the last 60 minutes of data. The two boxes to the right of the ‘Set Scales’ button normally display the mean and standard deviation of the measurements and these statistics can be cleared/reset by the adjacent ‘Clear’ button. However, when zero-power extrapolation is enabled, these are replaced by the last calculated zero-power value and its associated uncertainty (calculated from the standard deviation of each set of measurement data). The ‘Clear’ button is replaced by the ‘Details’ button:



After enabling zero-power extrapolation, it can take many minutes before the first measurement data sets have been collected and the zero-power value calculated. Press *Details* to open a window and see the status of the measurement sequence:



Press *Close* to return to the main window.

To save the data press *Start Save*, you will then be offer the choice of saving to the *Internal* memory or an *External* USB flash drive ("memory stick"). If you choose the internal memory, you can backup the data to an external USB flash drive later (see section 3.7.9 for details).

The 'raw' data is saved in a comma delimited ASCII file (together with microK settings information) with the extension ".dat". The 'processed' zero-power

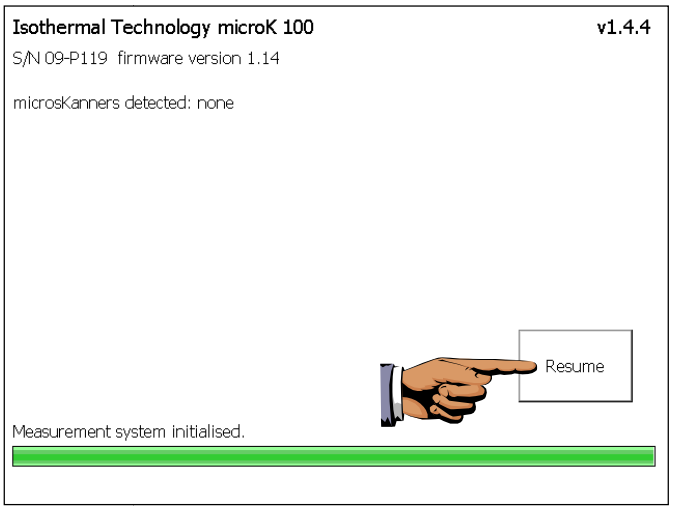
measurements (together with microK settings information) is saved in a comma delimited ASCII file with the extension ".zpc". These files can be transferred to a PC and analysed using Excel™ (see section 3.7.9 for details).

Tip: You can connect a calibrated SPRT to channel 3 in order to monitor the temperature of the external reference resistor simultaneously (for lowest uncertainty, use the external reference resistor on channel 2 rather than the microK's internal resistance standards as the reference resistance for this SPRT).

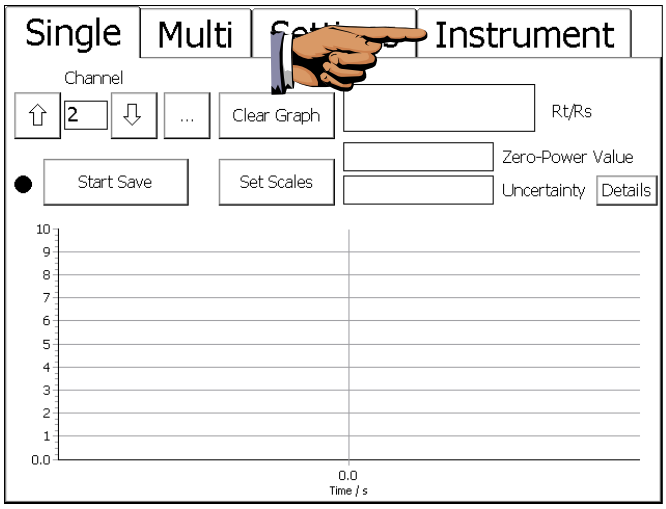
2.2 Measuring Temperature with an SPRT

The microK can be used with a calibrated SPRT to measure temperature with extremely low uncertainty. For lowest uncertainty, use an external DC or AC/DC resistance reference standard maintained at a constant temperature in an oil bath (or similar resistor maintenance system) as the reference resistor rather than the internal resistance standards.

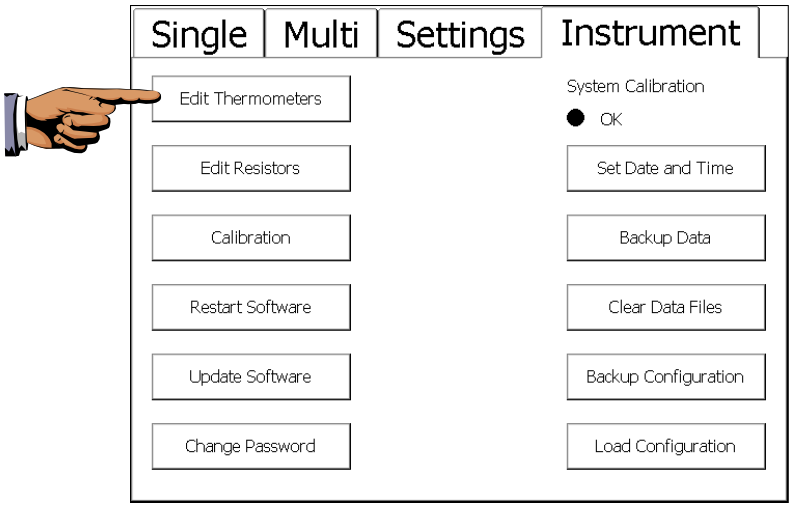
From start-up, press *Resume* to restart your microK:



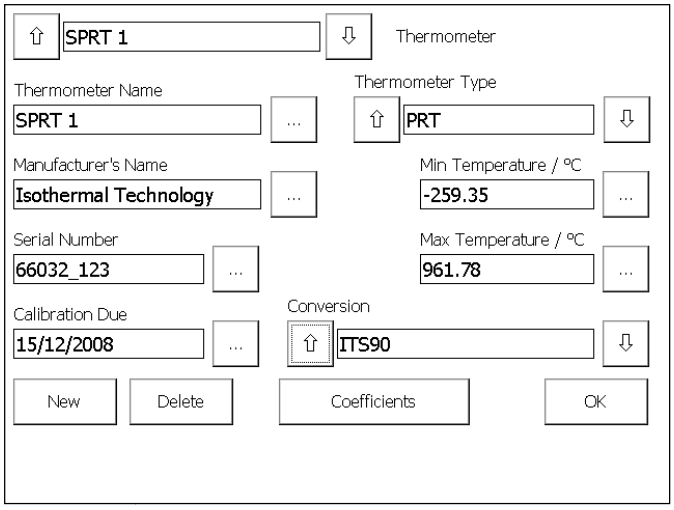
Before making any measurement, you will have to enter information about the SPRT and reference resistor into the microK's database. When the main window opens, press the *Instrument* tab:



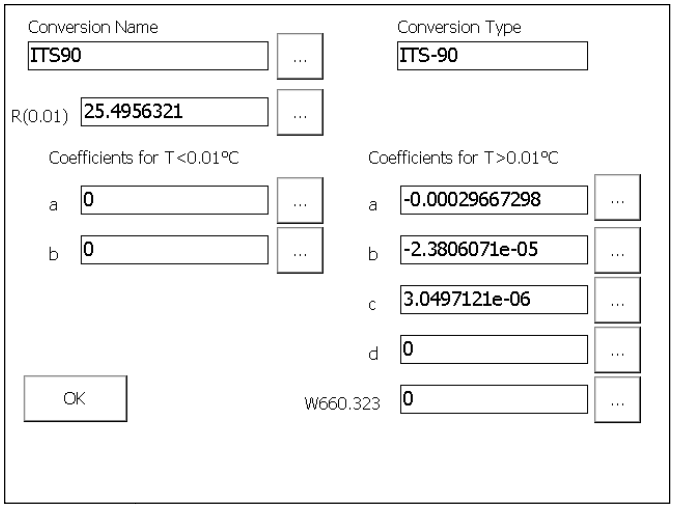
In the *Instrument* tab, press *Edit Thermometers*:



You will be prompted to enter the password (set to "1234" initially, but this should be changed before using the microK in a real measurement/calibration application to ensure security – see section 3.7.5.2). Enter the password to open the resistor database window. Press *New* to create a new thermometer entry in the database and enter data by pressing the up/down or ellipses buttons by each field:

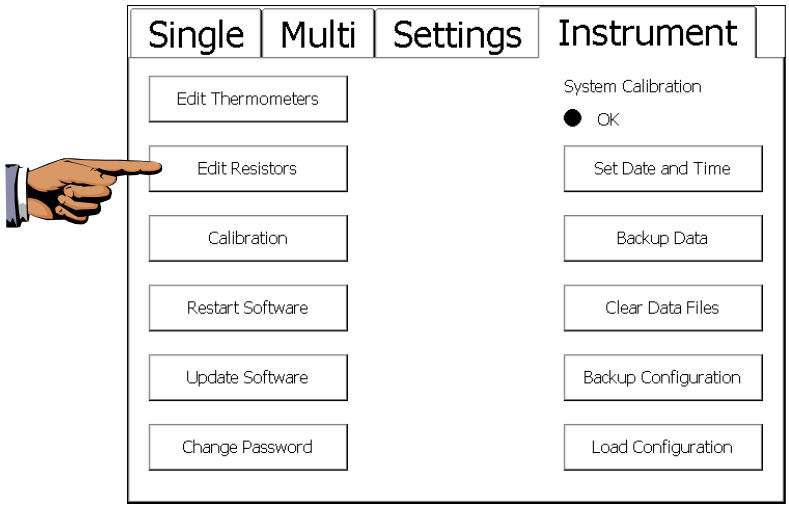


Press *Coefficients* and enter the calibration coefficients for the SPRT by pressing the ellipses buttons by each field and entering the data in the numeric entry window that appears:

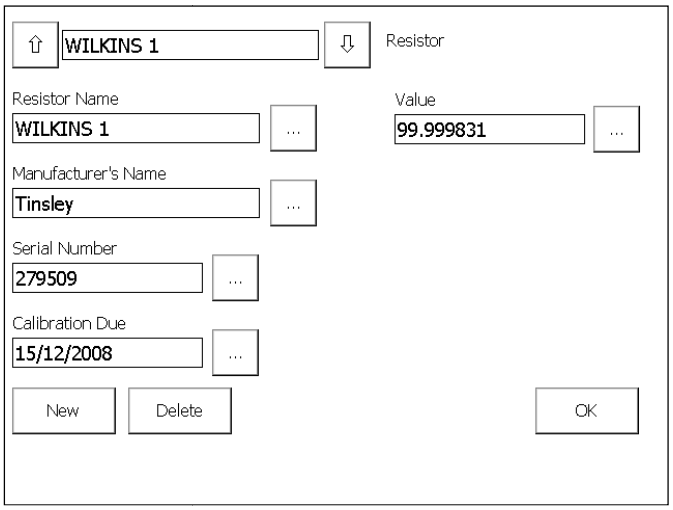


As SPRTs/PRTs drift during use, the proportional change in resistance is substantially the same at all temperatures. If you periodically measure the SPRTs resistance at the water triple point (0.01°C) and enter this value into this coefficients windows, you will improve measurement uncertainty significantly.

Press *OK* to close these windows and return to the main window. In the *Instrument* tab, press *Edit Resistors*:



You will be prompted to enter the password (set to "1234" initially). Enter the password to open the resistor database window. Press *New* to create a new resistor entry in the database and enter data by pressing the ellipses button by each field:

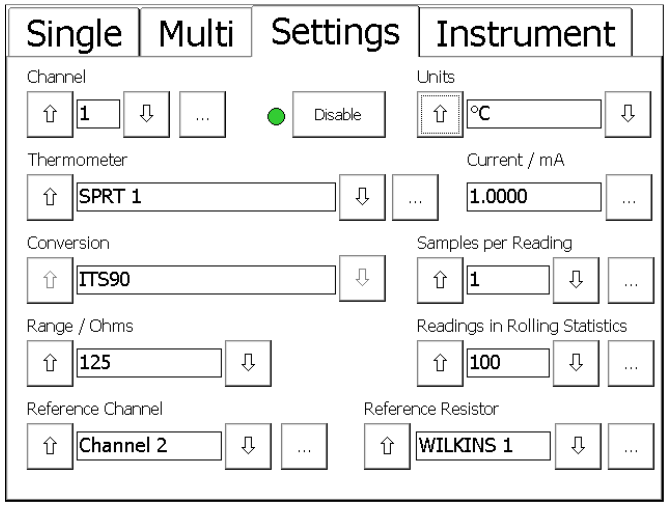


Press *OK* to close the resistor window.

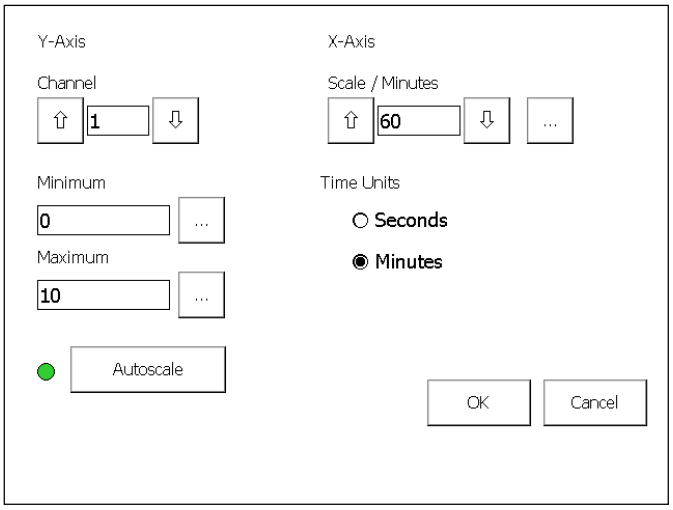
Connect the SPRT to channel 1 (see section 4.2 for details on how to connect 4-wire PRTs) and the reference resistor to channel 2.

Press the *Settings* tab in the main window and disable channels 2 and 3 (this will speed up measurements on channel 1, which we will be using) by using the up/down buttons by the *Channel* box to select these channels and pressing

Disable. Use the up/down buttons to return to channel 1. Use the up/down or ellipses buttons by each box to select the required settings for the SPRT:



Press the *Single* tab to see the measurements in numeric and graphical form. Set the graph scales by pressing *Set Scales*. This opens the graph scales window. Ensure that autoscaling is turned on (press *Autoscale* to toggle autoscaling on/off, the status of autoscaling is shown by the adjacent indicator). Use the radio and up/down (or ellipses) buttons to set the x-axis to 60 minutes:



Press *OK* to return to the main window. The measurement system will now accumulate data and after 60 minutes the graph will begin to scroll to show the last 60 minutes of data.

To save the data press *Start Save*, you will then be offered the choice of saving to the *Internal* memory or an *External* USB flash drive ("memory stick"). If you choose the internal memory, you can backup the data to an external USB flash drive later (see section 3.7.9 for details).

The data is saved in a comma delimited ASCII file (together with microK settings information) with the extension ".dat". This file can be transferred to a PC and analysed using Excel™ (see section 3.7.9 for details).

Tip: You can perform a comparison calibration on a PRT by connecting it to channel 3 and measuring its resistance and the temperature of the reference SPRT as they are immersed in number of temperature sources (fixed-point cells, liquid baths of block baths). Using this data, the calibration information for the PRT can be generated.

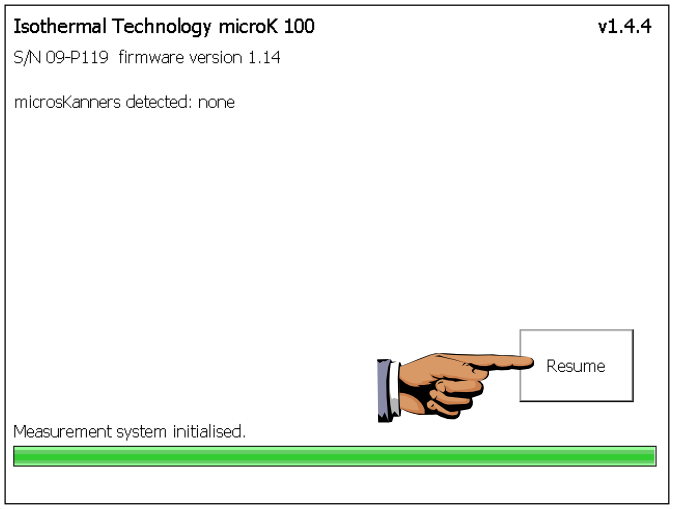
Tip: In comparison calibrations, any error in the value of the reference resistor causes an error in the measured resistance of the PRT to be calibrated but also causes a corresponding error in the temperature measured using the SPRT (provided that the same reference resistor is used for both thermometers). These correlated errors mean that the measured resistance-temperature point corresponds to a valid point further up or down the PRT's resistance versus tempertaure characteristic and therefore does not cause any calibration error (provided that the slope of the resistance versus temperature characteristic is the same for the PRT and SPRT). Any small difference between the slope of the PRT and SPRT will lead to an error, this is calculable and should be included in any uncertainty budget.

In effect, it is only necessary to know the temperature of the SPRT and the ratio of the resistance of the PRT to that of the SPRT on order to transfer the calibration from the SPRT to the PRT. It is common practice to measure the ratio of the resistance of the two thermometers rather than measure their individual resistances in a comparison calibration. This has the advantage of reducing the calibration uncertainty be elimintating one of the measurements involved.

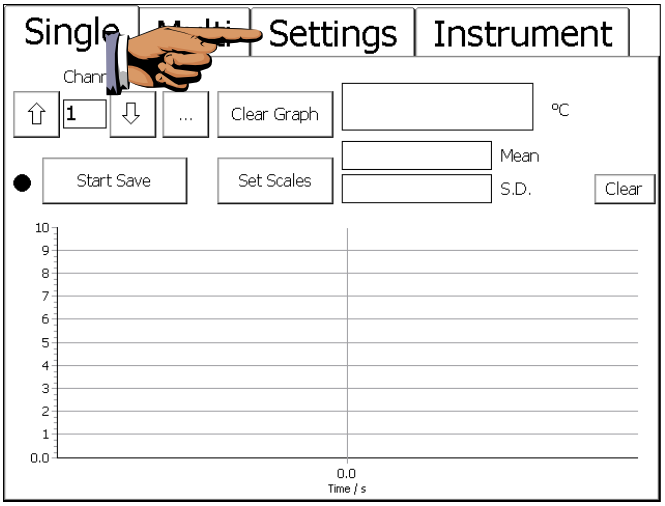
2.3 Measuring the Output from a Thermocouple

The microK is capable of measuring temperature using a thermocouple. But a more common use would be to calibrate a thermocouple against another more accurate thermocouple or an SPRT. This tutorial describes how to measure the output voltage from a thermocouple in volts.

From start-up, press *Resume* to restart your microK:

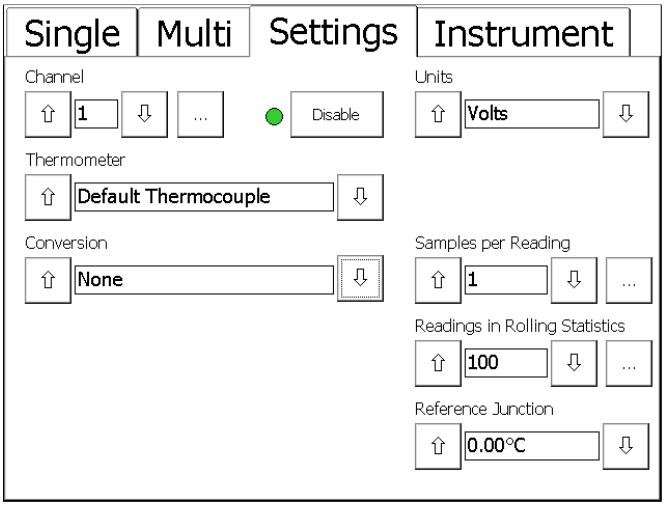


When the main window opens, press the *Settings* tab:



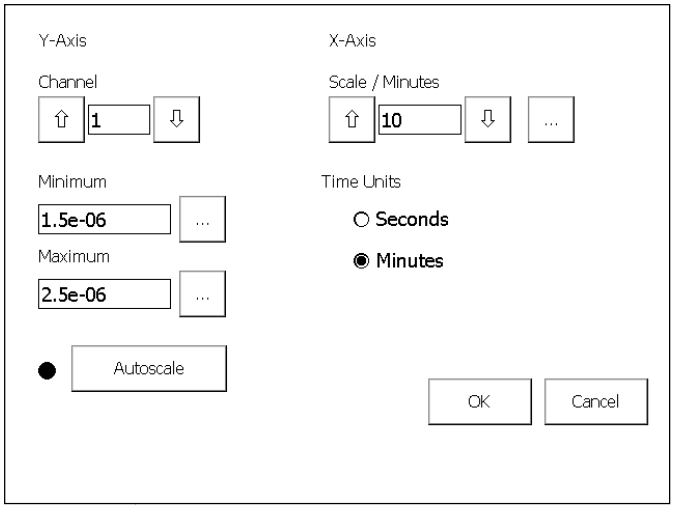
In the *Settings* tab disable channels 2 and 3 (this will speed up measurements on channel 1, which we will be using) by using the up/down buttons by the *Channel* box to select these channels and pressing *Disable*. Use the up/down buttons to

return to channel 1. Use the up/down buttons by each box to select the required settings:

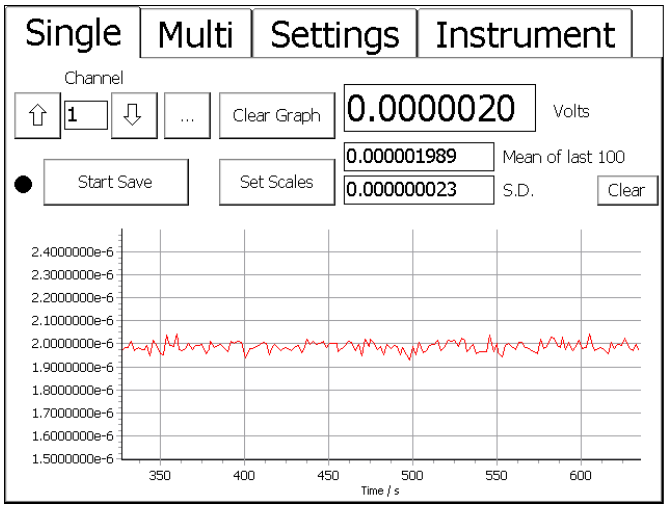


The 'Conversion' and 'Reference Junction' setting are not important since we are only going to measure the output in volts.

Connect the thermocouple to channel 1 (see section 4.5 for details on how to connect thermocouples) and place the reference junction in an ice-point reference. Press the *Single* tab to see the measurements in numeric and graphical form. Set the graph scales manually by making a note of the current *Mean* value and pressing *Set Scales*. This opens the graph scales window. Ensure that autoscaling is turned off (press *Autoscale* to toggle autoscaling on/off, the status of autoscaling is shown by the adjacent indicator). Use the ellipses buttons to set the y-axis limits to be 0.5 µV above and below the current mean value. Use the radio and up/down buttons to set the x-axis to 10 minutes:



Press *OK* to return to the main window. The measurement system will now accumulate data and after 10 minutes the graph will begin to scroll to show the last 10 minutes of data:



Tip: The microK provides reference functions for standard thermocouples to convert the measured voltage to temperature. You can also enter a third-order polynomial as the individual deviation function for a calibrated thermocouple (see section 3.7.1).

3 Driving your microK

3.1 Introduction

The operator interface for the microK is provided through the touch screen and colour display. The software is written in Microsoft's new C# language and runs under the Windows CE™ operating system. This provides a familiar and easy to use interface.

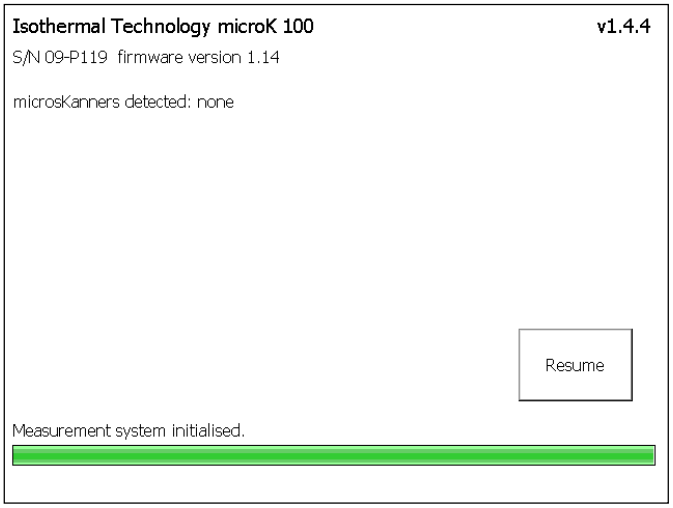
The buttons in the microK software have been sized and positioned to allow you to operate the instrument with your finger. If numeric or alphanumeric data needs to be entered, a 'soft' keyboard window appears. If you are unfamiliar with touch screen devices such as PDAs, you may initially feel that the touch screen interface is slow compared with using a mouse and keyboard, but with a little practice you should quickly become comfortable with the technology and appreciate its benefits. However, if you prefer to use a USB mouse or keyboard, you can simply plug these into the USB connector on the front panel. They will immediately become active provided they use the standard class drivers built into the Windows CE™ operating system used in the microK. To use more than one USB device, simply plug a USB hub into the front panel connector.

Calibration data entered into the microK's database is password protected and includes recalibration dates (the microK will alert you if you try to use a thermometer or reference resistor after its recalibration date). This feature ensures the integrity of your measurements and helps you to comply with the requirements of accreditation bodies.

3.2 The Start-Up Window

When power is applied to the microK, it goes through a Windows CE™ boot sequence that loads the operating system and then starts the microK application. The start-up window then appears showing the microK's model and serial number together with the version numbers for the measurement system firmware and microK software used. The window also lists the details of any "microsKanner" multiplexers connected to the microK (the microsKanner

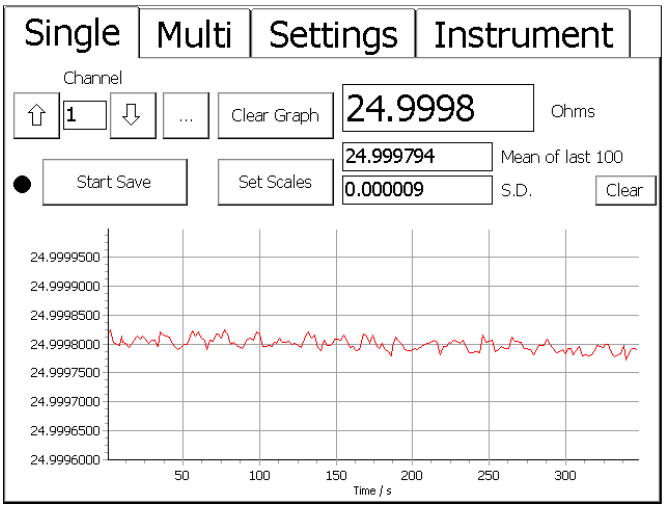
manual describes how to use “microsKanner” multiplexers with your microK bridge). The start-up window contains the Resume button:



Resume: Pressing the *Resume* button places the microK in the state it was in prior to its last power down. Before pressing *Resume*, make sure that any thermometers attached will not be damaged by the sense currents that will be applied (the last values used). If there is a problem, disconnect your sensors before proceeding and then reconnect them after changing the sense currents to the required value.

3.3 The Main Window

Having pressed *Resume* in the start-up window, the user is presented with the main window:



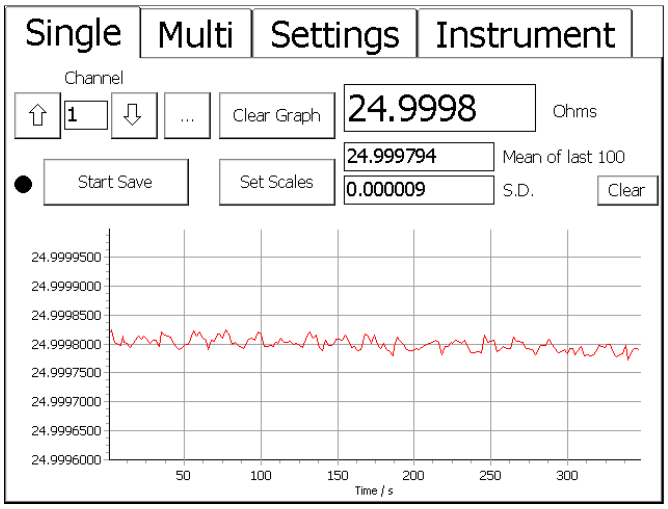
All functions to control the microK are available in this window, which is divided into four tabs:

Single	displays a single channel in numeric and graphical form
Multi	displays all three channels in numeric form
Settings	allows you to configure the channels to perform the required measurement
Instrument	allows you to enter information on the thermometers and reference resistors used with the instrument into its database. It also allows you to save/load measurement data and instrument configurations in the database and to change instrument settings such as time/date and the security password

The main window opens with the *Single* tab selected.

3.4 The Single Tab

Select this tab to see a single channel in both numeric and graphical form:



The numeric display shows the last reading together with the mean and standard deviation of the most recent readings (the number or readings in the statistics is set in the *Settings* tab). If the zero-power extrapolation feature is being used, the mean and standard deviations are replaced by the "Zero-power Value" and "Uncertainty" values and the *Clear* button is replaced by the *Details* button (see section 6).

The numeric and graphical outputs are updated as new readings are made. The time between readings depends on the settings for that channel and any other channels that are also enabled. This can vary between 2 seconds and 5 minutes. The sample time for each channel is 2s, so if all three channels are enabled each channel will be updated every 6s.

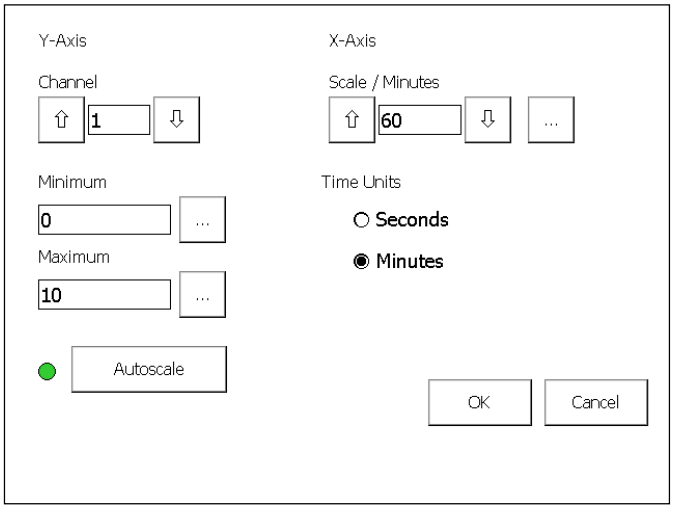
Channel box: Use the up/down buttons by the *Channel* box to select the channel you wish to view. Alternatively press the ellipses button to open a numeric entry window and select the channel directly. The ellipses button is particularly useful when the microK is used with microsKanner multiplexers, which can provide up to 90 expansion channels. You can only view channels that are enabled, so if a channel is disabled in the *Settings* tab it will not appear in the sequence and will not be measured. This means that the up/down buttons have no effect if only one channel is enabled.

Clear Graph: Press *Clear Graph* to clear the graph and re-start the autoscaling feature. This can be used to eliminate the effect of a large transient result

(perhaps caused when changing connections to the thermometer) on the autoscaling function.

Clear button: Press *Clear* to clear (reset) the statistics. If the microK is configured to perform a zero power extrapolation on the selected channel, the clear button is replaced by a *Details* button (see section 6 for further details on this feature).

Set Scales button: Press *Set Scales* to open a new window and set the x and y axes for the graphical output:



In this window, use the up/down buttons by the *Channel* box to select the channel whose scales you wish to change (the window opens with the currently displayed channel selected). Use the radio buttons to select either *Seconds* or *Minutes* as the units. Use the up/down buttons by the *Scale / Minutes* box to change the x-axis (time) scale (the same x axis scale is used for all channels). Or, press the ellipses button to open a Numeric Keypad window and enter the required scale directly. Any value between 1 second and 1000 minutes (inclusive) may be used.

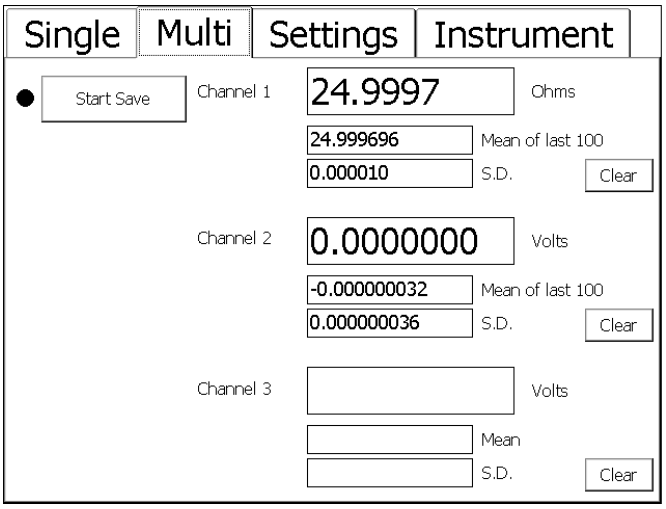
Use the ellipses buttons by the *Minimum* and *Maximum* boxes to open a Numeric Keypad window and set the y-axis scale. Alternatively, press *Autoscale* to scale the y-axis so that it will show all the readings. The indicator by the *Autoscale* button shows whether autoscaling is active.

Start Save button: Press *Start Save* to record all the measurements being made. You will then be offered the choice (buttons) of storing the data to the *Internal* memory (solid state drive) or an *External* USB flash drive. Data stored to the internal memory is preserved when power is removed and can subsequently be transferred to an external USB flash drive using the *Backup Data* button in the *Instrument* tab (see section 3.7.9). The internal memory has a capacity of at least 1.8 GBytes, which will accommodate more than 70 million PRT readings or more than 4.5 years of continuous logging at the fastest rate. Select the destination for the data to open an Alpha-Numeric Keyboard window and enter a filename. An automatically incrementing default name (based on the last filename used) will appear in the entry box, press *OK* to accept this or use the backspace and alpha-numeric keys to enter your preferred filename. If you try to use a filename that has already been used, you will have to enter the password to proceed (see section 3.11 for details on password protection). The *Shift* key toggles the alpha keys between upper and lower case. The indicator by the *Start Save* button shows whether readings are being recorded to a file. The measurements are written to the file in comma delimited ASCII text form allowing easy importation into Microsoft Excel™ or other applications.

3.5 The Multi Tab

Select this tab to see all three channels in numeric form only.

The numeric display shows the last reading together with the mean and standard deviation for the most recent readings (the number or readings in the statistics is set in the *Settings* tab) for each of the channels that are enabled. If the zero-power extrapolation feature is being used, the mean and standard deviations are replaced by the “Zero-Power Value” and “Uncertainty” values and the *Clear* button is replaced by the *Details* button (see section 6).



The displayed values are updated as new readings are taken. The time between readings depends on the settings for that channel and any other channels that are also enabled. This can vary between 2 seconds and 5 minutes. The shortest measurement time is 2s, so if all three channels were enabled and working at this fastest rate each channel would be updated every 6s.

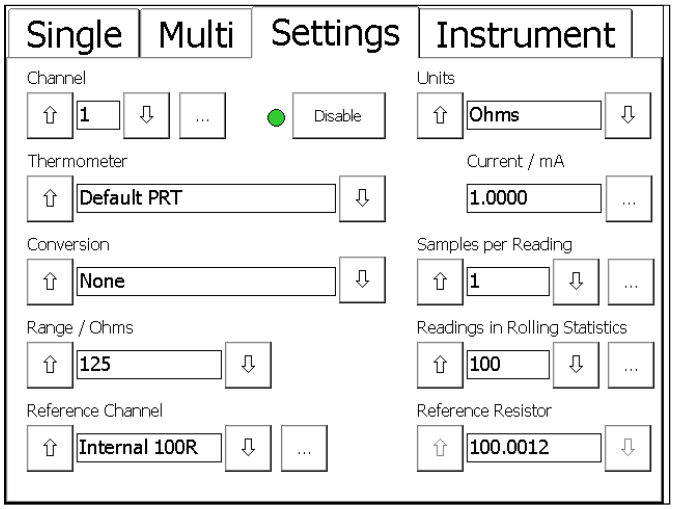
Clear buttons: Press the *Clear* button to clear (reset) the statistics for each channel.

Start Save: Press the *Start Save* button to record all the measurements being made. You will then be offered the choice (buttons) of storing the data to the *Internal* memory (solid state drive) or an *External* USB flash drive. Data stored to the internal memory is preserved when power is removed and can subsequently be transferred to an external USB flash drive using the *Backup Data* button in the *Instrument* tab (see section 3.7.9). The internal memory has a capacity of at least 1.8 GBytes, which will accommodate more than 70 million PRT readings or more than 4.5 years of continuous logging at the fastest rate. Select the destination for the data to open an Alpha-Numeric Keyboard window and enter a filename. An automatically incrementing default name (based on the last filename used) will appear in the entry box, press *OK* to accept this or use the backspace and alpha-numeric keys to enter your preferred filename. If you try to use a filename that has already been used, you will have to enter the password to proceed (see section 3.11 for details on password protection). The *Shift* key toggles the alpha keys between upper and lower case. The indicator by

the *Start Save* button shows whether readings are being recorded to a file. The measurements are written to the file in comma delimited ASCII text form allowing easy importation into Microsoft Excel™ or other applications.

3.6 The Settings Tab

Select this tab to configure each channel for the required measurements.



Channel box: Use the up/down buttons to select the channel you wish to configure. Alternatively press the ellipses button to open a numeric entry window and select the channel directly. The ellipses button is particularly useful when the microK is used with microsKanner multiplexers, which can provide up to 90 expansion channels.

Enable/Disable button: Use this button to enable or disable a channel. Disable unused channels to skip measurements on that channel and reduce the cycle time through the channels. The nearby indicator shows whether the currently selected channel is enabled.

Thermometer box: Use the up/down buttons to select the required thermometer. Initially this box will contain only default PRT, Thermocouple or Thermistor. You can use these entries for uncalibrated thermometer sensors. If you add thermometers to the microK's Thermometer Database (see section 3.7.1), these will also appear in the list within this box.

Conversion box: If the selected thermometer is one of the default types, you can use the up-down buttons to select a standard polynomial function for converting the thermometer's base measurement to temperature. If the selected thermometer is one that your have created in the Thermometer Database this box will be fixed and will be the conversion type defined for that thermometer.

Range box (PRTs and thermistors only): Use the up/down buttons to select the required range. The microK provides two ranges for resistance thermometers. The resistance ranges offered depends on the sense current (use the ellipses button by the *Current* box in this tab to change the current). Choose a resistance range that is greater than or equal to both the thermometer resistance and reference resistor value you intend to use.

Reference Channel box (PRTs and thermistors only): Use the up/down buttons to select the reference resistor used in the resistance measurement; either one of the internal reference resistors or the channel to which an external resistance standard is connected. Alternatively press the ellipses button to open the Reference Channel window and select the channel directly. The *External* button in this window allows you to select one of the microK's three external channels or any expansion channel provided by a microsKanner.

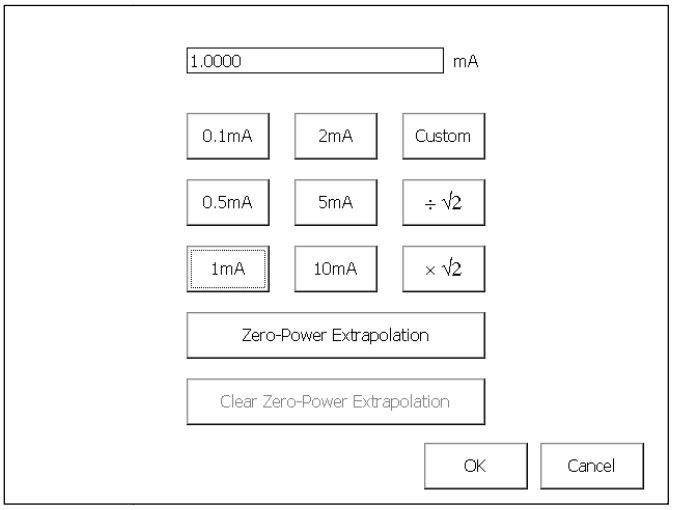
Reference Resistor box (PRTs and thermistors only): If an internal reference resistor was selected in the *Reference Channel* box, this box will show the calibrated value of that resistor. If one of the input channels was selected in the *Reference Channel* box, this box will contain a list of the reference resistors in the microK's database (entered using the *Edit Resistors* button in the *Instrument* tab – see section 3.7.2) and "Uncalibrated". Select the required resistor using the up/down buttons. Select "Uncalibrated" if you only want to make a resistance ratio measurement between two channels.

Reference Junction box (thermocouples only): This contains 0°C, 0.01°C and a list of any input channels that have been configured to measure temperature. Choose 0°C or 0.01°C if you are using an external reference junction in an ice-point bath or water triple point respectively. Choose one of the measurement channels if you want to measure the temperature of the reference junction with a

thermometer sensor on that channel. The software will not allow you to use a thermocouple channel as the reference junction sensor (to avoid circular dependencies). You must specify a thermometer sensor for the reference junction channel that includes temperature conversion otherwise it will not appear in the *Reference Junction* box.

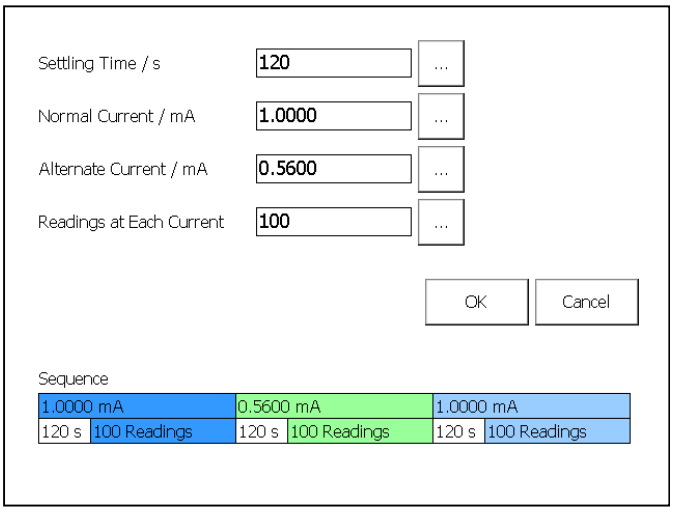
Units box: Use the up/down buttons to select the required units. The base units (resistance ratio "Rt/Rs" for PRTs or thermistors and "Volts" for thermocouples) are always available. "Ohms" will also be available (for PRTs and thermistors) if the value of the reference resistor is available (*Reference Resistor* not set to "Uncalibrated"). If the thermometer sensor chosen has a temperature conversion specified, then temperature units °C, °F and K are also available.

Current box: Press the ellipses button to change the sense current. Use the buttons in the window that then opens to select the required sense current:



The standard PRT sense currents are available directly through the buttons provided. Press the *Custom* button to specify a different value (range 0 to 10mA); this will then open a Numeric Keypad window.

Buttons for ÷√2 and ×√2 are included to make manual extrapolation to zero power easier. Uniquely, the microK can be configured to automatically change the current between two values and extrapolate to determine a zero-power resistance. Press *Zero Power Extrapolation* to define the measurement sequence:



Use the ellipses button to specify the two currents used, the number of readings taken at each current and the settling time allowed after the current is changed. The 'Sequence' details at the bottom of the window show the resulting measurement sequence. The resistance is measured at normal current, the alternate current and then returns to the normal current with settling delays after each current change. Section 6 gives further details of the zero power extrapolation feature.

Press *Clear Zero Power Extrapolation* in the current window to cancel the zero power measurement sequence and return to a steady measurement current.

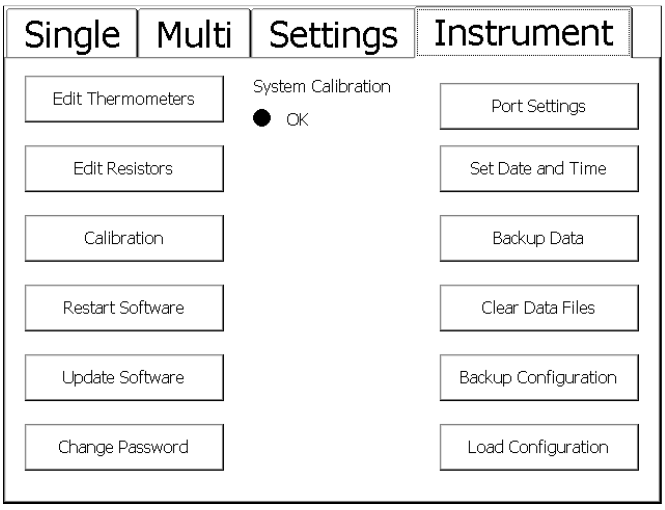
Samples per Reading box: Use the up/down buttons to select the number of samples you want to average together to form a single reading. Alternatively, press the ellipses button to open a Numeric Keypad window and enter the required number directly. The number of samples may be between 1 and 100 inclusive.

Increasing the number of samples will slow down the rate at which readings are made, but will also reduce the uncertainty associated with these readings (as shown by the standard deviations reported in the "Single" and "Multi" tabs). This uncertainty reduction is proportional to the square-root of the number of samples (for example: selecting 16 samples per reading will reduce the uncertainty associated with each reading by a factor of 4).

Readings in Rolling Statistics box: Use the up-down buttons to select the number of samples in the rolling statistics. Alternatively press the ellipses button to open a Numeric Keypad window and enter the value directly. Values between 1 and 1000 (inclusive) may be used.

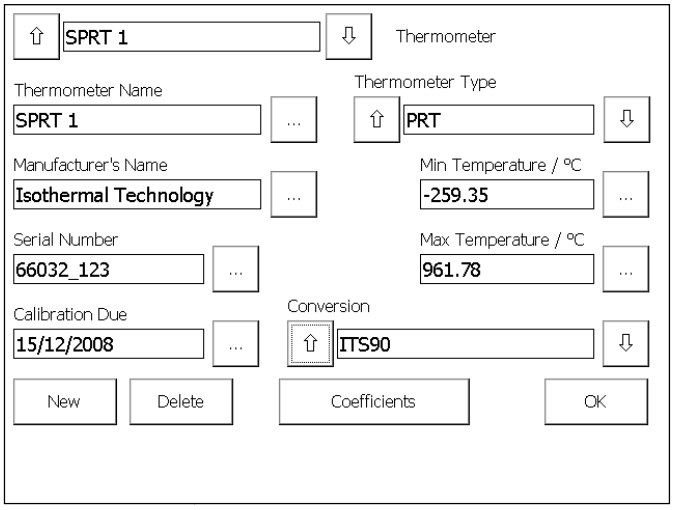
3.7 The Instrument Tab

Select this tab to enter information into the microK's database (for thermometers and reference resistors), adjust instrument settings (GPIB or IP address, time, date and password), update the software or firmware and manage data:



3.7.1 Edit Thermometers

Press *Edit Thermometers* to create, edit or delete a thermometer in the database. You will be prompted to enter the password in order to proceed.



Thermometer box: Use the up/down buttons to select the thermometer you wish to edit or delete. Alternatively press the *New* key to create a new thermometer entry. The default thermometer types are included in the list but cannot be edited or deleted.

Thermometer Name box: This box contains the name of the selected thermometer. Press the ellipses button by the box to open an Alpha-Numeric Keyboard window and enter/edit a name. The *Shift* key toggles the alpha keys between upper and lower case.

Manufacturer's Name box: This box contains the manufacturer of the selected thermometer. Press the ellipses button by the box to open an Alpha-Numeric Keyboard window and enter/edit a name. The *Shift* key toggles the alpha keys between upper and lower case.

Serial Number box: This box contains the serial number of the selected thermometer. Press the ellipses button by the box to open an Alpha-Numeric Keyboard window and enter/edit a serial number. The *Shift* key toggles the alpha keys between upper and lower case.

Calibration Due box: This box contains the date when calibration is due for the selected thermometer. Press the ellipses button by the box to open a date entry window and enter a date. The ellipses buttons by the *Day*, *Month* and *Year* boxes in the date entry window open a Numeric Keypad window. Dates are checked for validity (including leap years) for dates up to 31st December 2099.

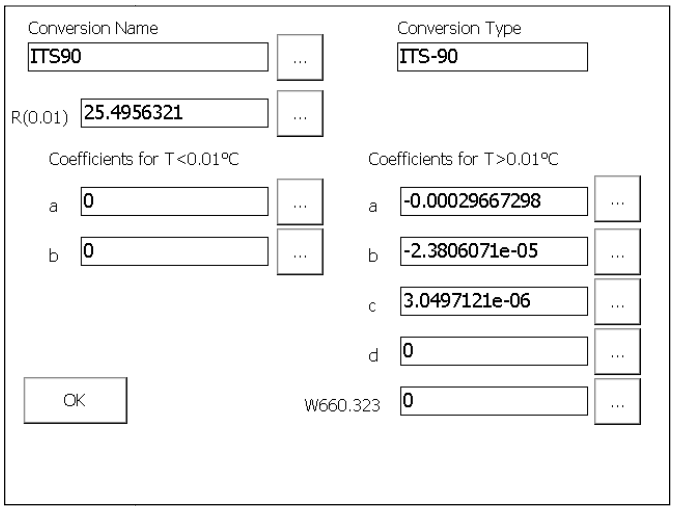
Thermometer Type box: This box contains the type of thermometer (PRT, Thermocouple or Thermistor). If you are creating a new thermometer entry, use the up/down buttons to select the thermometer type.

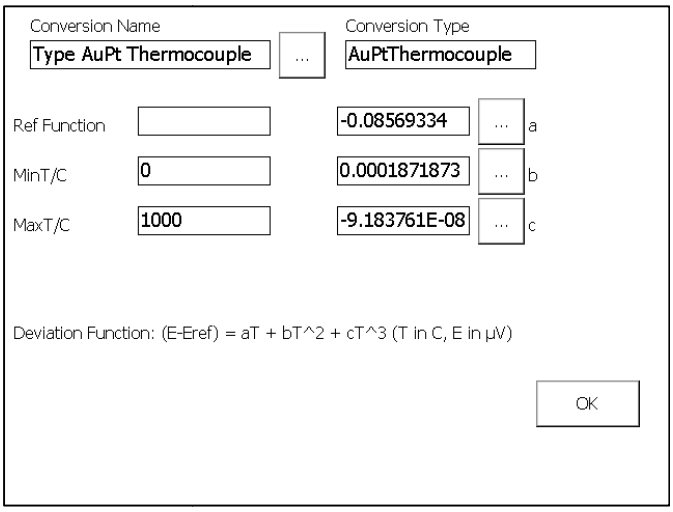
Min Temperature box: This box contains the minimum operating temperature for the selected thermometer. Press the ellipses button by the box to open a Numeric Keypad window and enter the minimum operating temperature for the thermometer.

Max Temperature box: This box contains the maximum operating temperature for the selected thermometer. Press the ellipses button by the box to open a Numeric Keypad window and enter the maximum operating temperature for the thermometer.

Conversion box: This box contains the conversion to temperature used for the selected thermometer. If you are creating a new thermometer entry, use the up/down buttons to select the required conversion.

Coefficients button: This button opens a window that allows you to enter the coefficients required for the temperature conversion. In the case of ITS-90 or thermocouples, these are the coefficients for the deviation function (the base conversion coefficients are fixed):





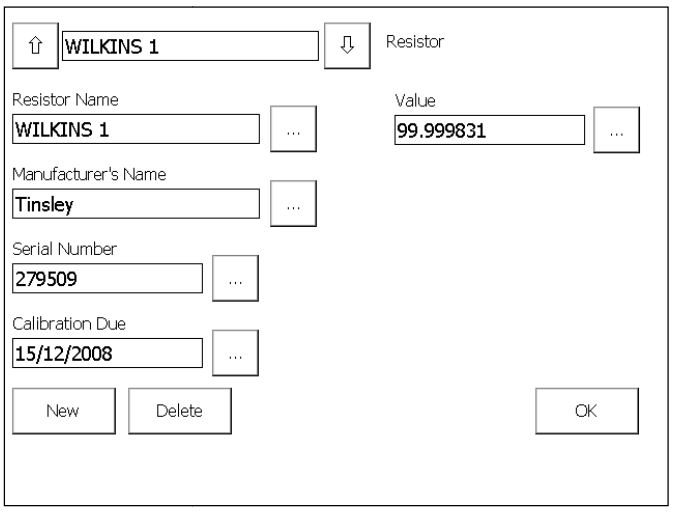
New button: Press this button to make a new thermometer entry into the microK's database.

Delete button: Press this button to delete the selected thermometer (or the current entry for a new thermometer) from the database.

OK button: Press this button to confirm the changes and close the window.

3.7.2 Edit Resistors

Press the *Edit Resistors* button to create, edit or delete a reference resistor in the database. You will be prompted to enter the password in order to proceed.



Resistor box: Use the up/down buttons to select the reference resistor you wish to edit or delete. Alternatively press the *New* key to create a new reference

resistor entry. The internal reference resistors are included in the list but cannot be edited or deleted.

Resistor Name box: This box contains the name of the selected reference resistor. Press the ellipses button by the box to open an Alpha-Numeric Keyboard window and enter a name. The *Shift* key toggles the alpha keys between upper and lower case.

Manufacturer's Name box: This box contains the manufacturer of the selected reference resistor. Press the ellipses button by the box to open an Alpha-Numeric Keyboard window and enter a name. The *Shift* key toggles the alpha keys between upper and lower case.

Serial Number box: This box contains the serial number of the selected reference resistor. Press the ellipses button by the box to open an Alpha-Numeric Keyboard window and enter a serial number. The *Shift* key toggles the alpha keys between upper and lower case.

Calibration Due box: This box contains the date when calibration is due for the selected reference resistor. Press the ellipses button by the box to open a Date Entry window and enter a date. The ellipses buttons by the *Day*, *Month* and *Year* boxes in the Date Entry window open a Numeric Keypad window. Dates are checked for validity (including leap years) for dates up to 31st December 2099.

Value box: This box contains the calibrated value for the selected reference resistor. If you are creating a new reference resistor entry, press the ellipses button to open a Numeric Keypad window and enter the calibrated resistance value (in ohms).

New button: Press this button to make a new reference resistor entry into the microK's database.

Delete button: Press this button to delete the selected reference resistor (or the current entry for a new reference resistor) from the database.

OK button: Press this button to confirm the changes and close the window.

3.7.3 Calibration

Press *Calibration* to open a Date Entry window and set a recalibration date for your microK. The microK will warn you if you attempt to use it past this recalibration date (you can disregard the warning and continue to use it, but the warning will continue to re-appear every hour until the out-of-calibration issue is resolved).

3.7.4 Restart Software

Press the *Restart Software* button to restart the microK software. This is useful if you have added or removed microsKanners and want to re-invoke the automatic discovery process without cycling the power.

3.7.5 Update Software

The software in the microK provides the user interface and controls the instrument. It can easily be updated in-situ.

Press the *Update Software* button to update the software in your microK. The new application (microk.exe) should be located in the root directory of a USB flash drive connected to the front panel USB connector. You will be warned that this operation will restart the software, press *Yes* to continue. If the software finds a more recent software version on the flash drive you will be advised of the version levels and offered the opportunity to update to the later version. You will be prompted to enter the password before proceeding. If the flash drive does not contain a more recent version, the software will simply restart.

The software automatically checks any USB flash drive connected to the front panel at start-up. If a more recent software version is found, you will be offered the opportunity to upgrade.

3.7.5.1 Update Firmware

As well as the 32-bit processor on which the microK software runs to provide the operator interface, the microK also contains an 8-bit processor that provides low-level control of the measurement hardware. We used the term “firmware” for the

program in the 8-bit processor to distinguish it from the software that provides the operator interface. This firmware can also be updated easily in-situ.

As with updating the software, press the *Update Software* button to update the firmware in your microK. The new firmware (microK100 version x_xx.hex) should be located in the root directory of a USB flash drive connected to the front panel USB connector. You will be warned that this operation will restart the software, press *Yes* to continue. If the software finds a more recent firmware version on the flash drive you will be advised of the version levels and offered the opportunity to update to the later version. You will be prompted to enter the password before proceeding. If the flash drive does not contain a more recent version, the software will simply restart.

In order to update the firmware you will be asked to turn the power off and then on again. This will start the firmware update, which takes approximately 3 minutes during which time a progress bar is displayed. If power is lost during the update, the process will restart automatically when power is restored. Once the update is complete the microK displays the normal start-up window.

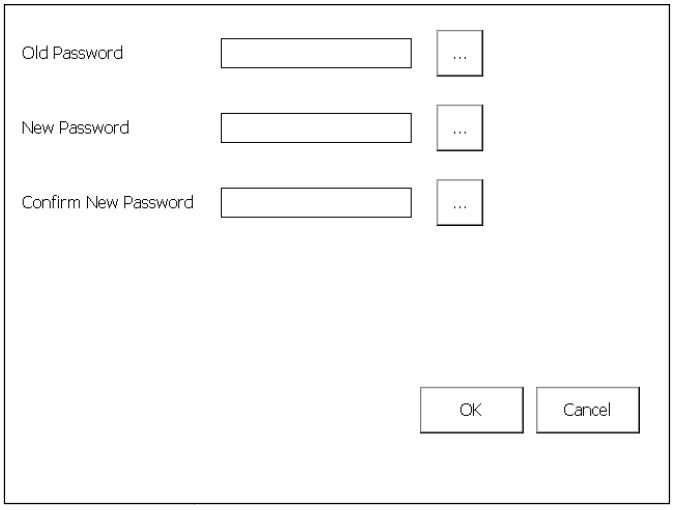
The software automatically checks any USB flash drive connected to the front panel at start-up. If a more recent firmware version is found, you will be offered the opportunity to upgrade.

3.7.5.2 Update Software and Firmware

The microK can only update either the firmware or software on each restart. If you wish to upgrade both, copy both files to the root directory of a USB flash drive connected to the front panel USB connector and invoke the update software feature twice. The firmware will be updated first.

3.7.6 Change Password

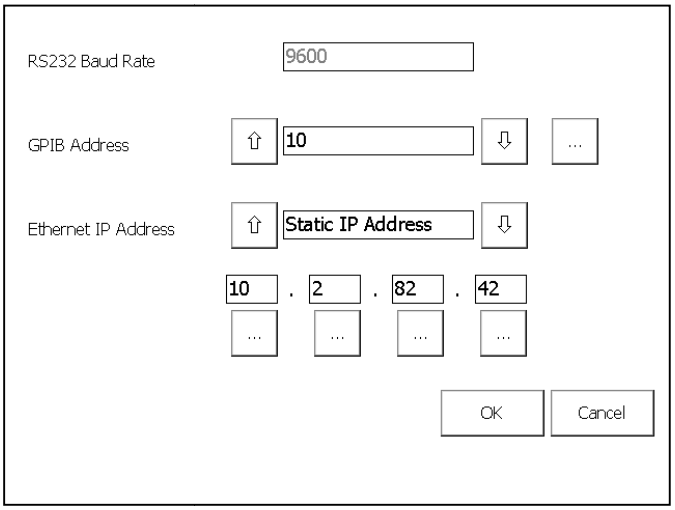
Press the *Change Password* button to change the security password. (see section 3.11 for details of password protected settings). A window will then open to allow you to change the password.



Enter the old password and the new one (twice to ensure that it has been correctly entered). Press the ellipses buttons by each of the password boxes to open an Alpha-Numeric Keyboard window and enter the relevant password. Your microK is shipped with the password set to "1234". This should be changed, for security reasons, before using your instrument in earnest.

3.7.7 Port Settings

Press *Port Settings* to view and change the microK's GPIB or IP address (the RS232 baud rate is fixed and cannot be changed) :

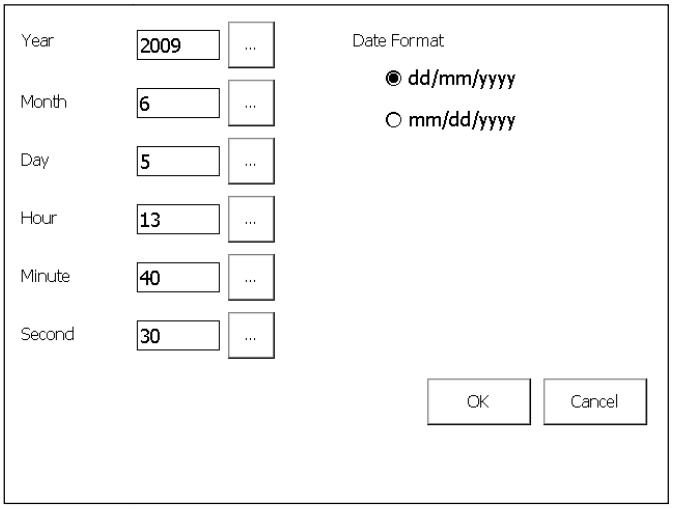


Use the up/down or ellipses buttons to change the GPIB address (valid range 1 to 30 inclusive). Use the up/down buttons to select either *"Static IP Address"* or

"Automatic (DHCP)" addressing for the Ethernet port. Use the ellipses buttons by each IP address byte to set a static IP address.

3.7.8 Set Date and Time

Press *Set Date and Time* to change the date and/or time. This opens a window to allow you to enter the current date and time and to select the date format (dd/mm/yyyy or mm/dd/yyyy):



Press the ellipses buttons by each box to open a Numeric keypad window and enter the required value.

Press *OK* to save the changes and close the window. Press *Cancel* to close the window without making any changes.

3.7.9 Backup Data

Press *Backup Data* to transfer data that has been saved to the internal memory (see section 3.4 or 3.5) to an external USB Flash Drive. You need to plug a USB Flash Drive into the front of the microK in order to use this facility (otherwise a "No external drive present" warning will appear). The operating system may take up to 20s to "find" the USB drive, so you may have to for a while after plugging in the drive before being able to backup data.

If a file with the same name is already present on the USB flash drive, you will be asked whether you wish to over-write it. To proceed, you will need to enter the password.

Files are transferred to the USB flash drive in directory:

\\microKData*serialnumber*\data

where "*serialnumber*" is the serial number of the microK used to make the measurements. This means that you can have duplicate filenames for measurements, provided they are made with different instruments.

The measurements are written to the file in comma delimited ASCII text form allowing easy importation into Microsoft Excel™ or other applications.

3.7.10 Clear Data Files

Press *Clear Data Files* to delete the data files from the internal memory, this frees up space for new files to be recorded. You will be prompted to enter the password before proceeding.

Unless you are sure that you do not need any of the files in the internal memory, you should transfer all files from the internal memory to a USB flash drive (see section 3.7.9) before using this feature.

3.7.11 Backup Configuration

Press *Backup Configuration* to save the current configuration (settings) of the microK. You will be prompted to enter the password before proceeding. You will then be offered the choice (buttons) of storing the configuration to the *Internal* memory (solid state drive) or an *External* USB flash drive. Press the required button to open an Alpha-Numeric Keyboard window and enter a name for the configuration.

Configurations stored to a USB flash drive are located in directory:

\\microKData*serialnumber*\backups

where "*serialnumber*" is the serial number if the microK. This means that you can have duplicate configuration names (filenames) for configurations provided they apply to different instruments. If you want to transfer a configuration from one microK to another, you will need to move the configuration file manually on the USB flash drive between the sub-directories for the two microKs.

3.7.12 Load Configuration

Press *Load Configuration* to load a configuration (settings) for the microK. You will be prompted to enter the password before proceeding. You will then be offered the choice (buttons) of loading the configuration from the *Internal* memory (solid state drive) or an *External* USB flash drive. Press the required button and then use the up/down buttons to select the required configuration. Press *OK* to load the configuration, or press *Cancel* to close the Window without loading the configuration.

3.8 Using the Thermometer Database

The microK contains a database that allows you to enter, review and edit information about the thermometers you use. You can then select a thermometer from this database and all the parameters associated with it will be loaded and used by the measurement system. This means that you do not need to enter information such as the calibration coefficients each time you use the thermometer and therefore avoids the associated risk of data entry errors.

The database also allows you to enter calibration due dates to ensure that you do not unwittingly use devices beyond their recalibration date. The microK will warn you if you attempt to use a thermometer past its recalibration date (you can disregard the warning and continue to use the thermometer, but the warning will continue to re-appear every hour until the out-of-calibration issue is resolved).

Enter data on the thermometers you use as reference standards or measurement devices into the microK's database (see section 3.7.1). You can then use one of these thermometers by selecting it in the *Thermometer* box in the *Settings* tab (see section 3.6).

The database allows you to enter the following information about the thermometer:

- Thermometer Name (the name you use to refer to the thermometer)
- Manufacturer
- Serial Number
- Calibration Due date
- Thermometer Type
- Minimum Temperature (operating)
- Maximum Temperature (operating)
- Conversion (algorithm for converting base reading to temperature)

Information in the database is password protected to help you comply with the requirements of accreditation bodies.

3.9 Using the Reference Resistors Database

The microK contains a database that allows you to enter, review and edit information about the reference resistors you use. You can then select a reference resistor from this database and all the parameters associated with it will be loaded and used by the measurement system. This means that you do not need to enter its value each time you use it and therefore avoids the associated risk of data entry errors.

The database also allows you to enter calibration due dates to ensure that you do not unwittingly use devices beyond their recalibration date. The microK will warn you if you attempt to use a reference resistor past its recalibration date (you can disregard the warning and continue to use it, but the warning will continue to re-appear every hour until the out-of-calibration issue is resolved).

Enter data on the reference resistors you use with your resistance thermometers into the microK's database (see section 3.7.2). You can then use one of these reference resistors using the *Reference Resistor* box in the *Settings* tab (see section 3.6).

The database allows you to enter the following information about the reference resistor:

- Resistor Name (the name you use to refer to the resistor)
- Manufacturer

- Serial Number
- Calibration Due date
- Value (calibrated value in ohms)

Information in the database is password protected to help you comply with the requirements of accreditation bodies.

3.10 Saving Instrument Configurations

You can save the current configuration (settings) for the microK using the *Backup Configuration* button in the *Instrument* tab (see section 3.7.11). This is useful if you use the microK in a number of different ways (for example at different times you may use it to perform fixed-point calibrations on single SPRTs and comparison calibrations of a thermocouple against two SPRTs). You can then reload the required configuration (see section 3.7.12) rather than having to enter all the settings for that particular measurement configuration individually.

3.11 Password Protection of Key Settings

All settings and parameters that affect measurements are password protected. This helps you to establish working procedures that meet the requirements of accreditation bodies and should alleviated some of the concerns that accreditation bodies have about the integrity of measurements.

You need to enter the password to perform the following tasks:

- create/edit/delete a thermometer database entry
- create/edit/delete a reference resistors database entry
- backup internal data to a USB flash drive
- overwrite a data file on the USB flash drive
- delete internal data files
- backup a configuration
- load a configuration
- change the password
- upgrade the software or firmware

4 Connecting Thermometer Sensors

4.1 The "Cable-Pod" Connectors

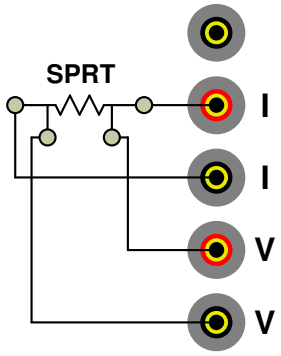
The Eichmann "Cable-Pod"™ connectors used on the microK have gold-plated tellurium-copper contacts. These generate exceptionally low thermal EMFs when connected to the copper terminations used on standards grade thermocouples.

The connectors accept 4mm plugs, bare wires or spade terminations. Additionally, they are spaced on 19mm (¾") pitch so that they can be used with standard 4mm-to-BNC adaptors (not supplied) for connecting to BNC terminated SPRTs. The mechanism is designed so that the clamping surface does not rotate as it clamps the wire in order to avoid damaging it.

The "Cable-Pod"™ mechanism is made from a high strength polymer but nonetheless may be subject to mechanical damage if the connectors are over tightened. Please tighten the terminals to a light "finger-tight" level in order to ensure that they are not subject to undue wear or premature failure. This is all that is required electrically – do not try to use the connector to provide strain relief or tension a cable.

4.2 Connecting PRTs (4-wire)

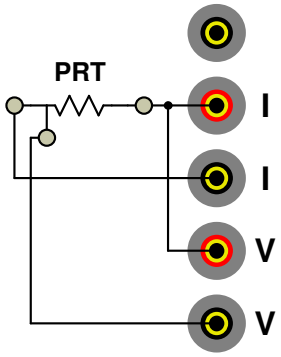
The microK's resistance measurement system is optimised for high accuracy, 4-wire resistance measurement. The PRT should be connected to the chosen input channel in accordance with the schematic shown on the microK's front panel, as follows:



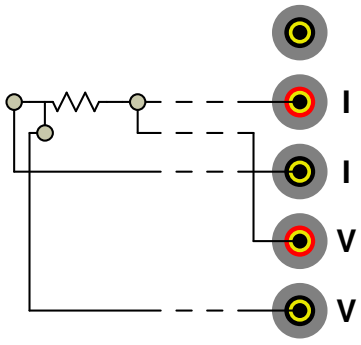
The top terminal should be connected to the screen of the SPRT's lead to minimise electrical noise picked up by the wires.

4.3 Connecting PRTs (3-wire)

The microK can be connected to 3-wire PRTs, although it will not automatically compensate for cable resistance. The two red terminals should be connected together and then connected to the 'single' end of the 3-wire PRT as follows:



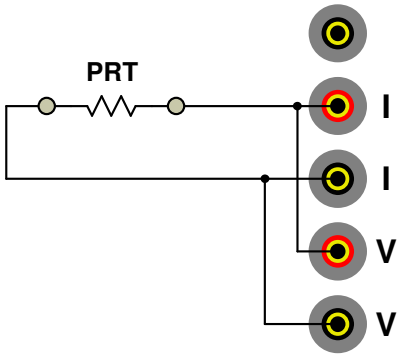
The connection to the 'single' end of the 3-wire PRT should be short (have a low resistance) in order to minimise the effect of lead resistance on the measurement. Alternatively, the connection to the 'single' end can use remote sensing (using the 4-wire measurement capability of the microK) to eliminate the effect of its lead resistance. In this arrangement, the current and voltage sense connections to the 'single' end are only joined close to the PRT.



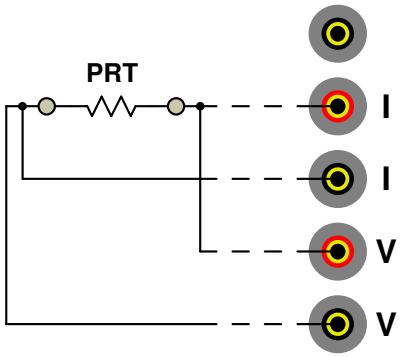
The top terminal should be connected to the screen of the PRT's lead to minimise electrical noise picked up by the wires.

4.4 Connecting PRTs (2-wire)

The microK can be connected to 2-wire PRTs. The two red and two black measurement terminals should be connected together and then connected to the PRT as follows:



The connections to the PRT should be short (low resistance) in order to minimise the effect of lead resistance on the measurement. Alternatively, the connections can use remote sensing (using the 4-wire measurement capability of the microK) to eliminate the effect of lead resistance completely. In this arrangement, the current and voltage sense connections are kept separate and are only joined close to the PRT:

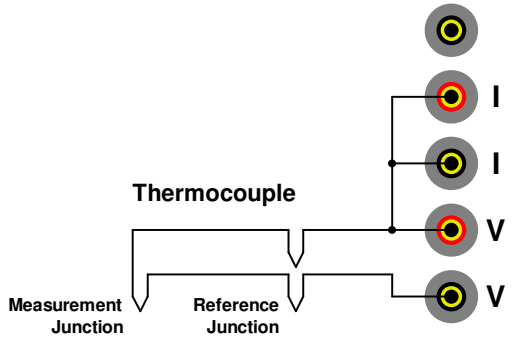


The top terminal should be connected to the screen of the PRT's lead to minimise electrical noise picked up by the wires.

4.5 Connecting Thermocouples (external Ice Point or WTP)

The microK's measurement system uses active guarding. As a result, the voltage measurement system is floating until it is connected to the sense current terminals. In order to measure the voltage on a thermocouple, the two current

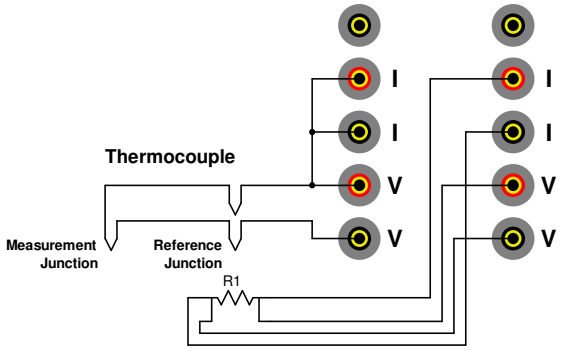
terminals should be connected to each other and to the red voltage sense terminal:



The most accurate thermocouple measurements are made with the reference junction immersed in an ice-point bath (or water-triple-point). The microK supports this arrangement by allowing you to specify the temperature of the reference junction as 0°C or 0.01°C (see section 3.6).

4.6 Connecting Thermocouples (using RJ compensation)

It is possible to measure the temperature of a thermocouples reference junction and compensate for the associated EMF. The reference junction can be measured using a PRT or thermistor connected to another measurement channel:

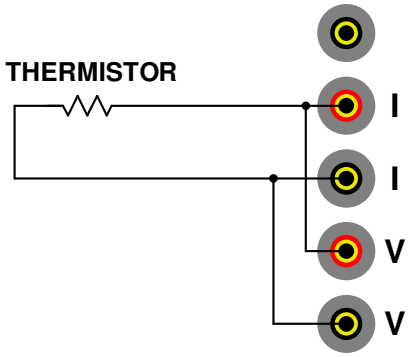


The microK supports thus arrangement by allowing you to use a temperature measured by another input channel as the reference junction temperature. This technique is less accurate than using an ice-point (or water-triple-point) due to the additional uncertainties associated with the PRT used to monitor the

reference junction and any temperature gradients that result in a difference between the temperature of the PRT and the reference junction.

4.7 Connecting Thermistors

The microK can be connected to thermistors using the same arrangement as for 2-wire PRTs (see section 4.4):



Because the resistance of thermistors used for temperature measurement is much higher than for PRTs, lead resistance is not normally a problem.

Use an external reference resistor with thermistors since the resistance of the internal standards is too low. Ideally, the value of the reference resistor should be similar to the thermistor's expected resistance range. Thermistors have much higher temperature coefficients than PRT, so the tolerances on the reference resistor are correspondingly less demanding, making them relatively inexpensive.

The top terminal should be connected to the screen of the thermistor's lead to minimise electrical noise picked up by the wires. The high resistance of thermistors makes them more prone to picking up electrical noise, it is therefore even more important to use a screened cable and connect this to the screen terminal on the microK than when using PRTs.

5 Good Practice Guidelines

5.1 Using Internal/External Reference Resistors

The microK's internal reference resistors are the best commercially available foil resistors, having a temperature coefficient of only 0.05ppm and a stability of 2ppm over 10 years. However, their temperature is not controlled and they will therefore not be as accurate as an external resistance standard maintained at a known temperature.

The microK is capable of measuring resistance ratio to better than ±0.1ppm so if you want to make use of this accuracy in performing a resistance measurement it is better to use a good external reference resistor such as a DC or AC/DC resistance reference standard maintained at a constant temperature in an oil bath. You will not be able to measure resistance to ±0.1ppm using the internal resistors.

The internal resistors are useful for less accurate work (PRT measurements to a few mK) or in comparison calibrations where any error in the value of the reference resistors causes a corresponding error in the temperature measured by the reference thermometer (which largely cancels out the effect of the error in the resistance measurement).

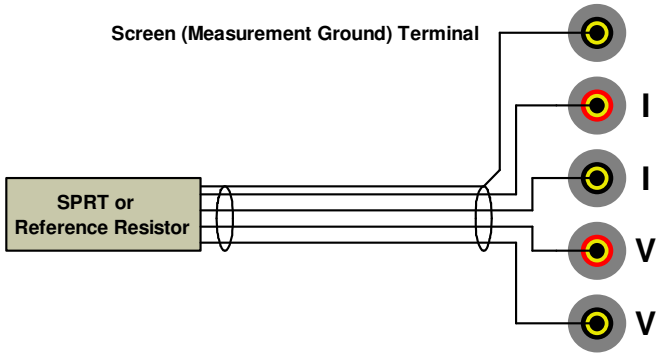
5.2 Making a Good Electrical Measurement

Although the microK is intended for use in temperature metrology, its base measurements are electrical (resistance or voltage). The limited sensitivity of PRTs and thermocouples means that in order to achieve uncertainties at the mK level, we need to make electrical measurements that rival those of a good electrical metrology laboratory. For example, for a 25Ω SPRT a 0.1mK temperature uncertainty corresponds to 10μΩ resistance uncertainty. With a 1mA sense current, this corresponds to a voltage uncertainty of 10nV.

The microK has been optimised for electromagnetic compatibility (minimising emissions and maximising immunity). However, since the microK is capable of

measuring to such low signal levels it is worthwhile adopting good electrical measurement practices. Here are a few guidelines:

- The most sensitive points are the inputs to the microK (measuring to better than 10nV). Whilst the microK will work satisfactorily with just a four wire connection to the PRT or reference resistor (using the voltage sense and current terminals marked “V” and “I” respectively), it is better to use a screened cable and to connect the screen to the measurement ground terminal above the input terminals:



  The screen should also be connected to the outer sheath of the SPRT (if it is metal clad) or the case of the reference resistor. The use of screened cables is more important when the microK is used with thermistors, which have a higher resistance than PRTs or thermocouples.
- Keep the cables to the microK input terminals away from other cables that might be sources of electrical noise (for example electrical supplies to furnaces).
- The insulation in high temperature furnaces (any that ‘glow’) begins to conduct at higher temperatures. This can cause high common-mode voltages on any thermometer in the furnace. Whilst the microK is designed to reject common-mode DC and AC signals (at both 50 and 60Hz), it is good practice to minimise them. It is common practice to use a metal equalising block in a furnace when performing comparison calibrations. This should be connected to the safety earth of the electrical supply (most furnaces designed for temperature metrology applications are fitted with a device to ‘earth’ the equalising block). Do not ‘earth’ the

equalising block to the screen/measurement ground terminals on the front panel of your microK as this is not connected to the safety earth of the electrical supply.

- Provide a 'clean' electrical environment in your temperature laboratory. It may be useful to filter your electrical supply into the laboratory especially if other heavy electrical machinery is being used nearby on the same supply (the microK has very good immunity to electrical noise conducted along the electrical supply, but other equipment in your laboratory may be more sensitive). Avoid using sources of electrical signals or noise in your laboratory, examples include furnaces with triac controls (especially those that 'chop' the electrical supply part way through a cycle – better controllers switch only at the zero-crossing point to 'chop' only whole cycles) and mobile phones (the microK is not significantly affected by mobile phones, but other equipment may be more sensitive).

5.3 Looking After Your microK

Your microK is a precision electronic instrument intended for indoor use in a laboratory or office environment. Nonetheless, it has been designed to be as robust as is practical and will provide many years of service, provided it is properly maintained.

We recommend that you return your microK to Isothermal Technology or one of our approved service centres on an annual basis for calibration. Isothermal Technology has developed a calibration kit for the microK. Contact Isothermal Technology or one of our appointed distributors if you wish to purchase a kit to calibrate the microK yourself. The microK should require little maintenance between calibrations other than routine cleaning.

Under no circumstances should you use sharp or unsuitable objects (such as ball-point pens) on the touch screen as this will lead to premature failure. It is also a good idea to ensure that you have clean hands when using the touch screen. You should ensure that you do not have contaminants such as adhesives or solvents on you fingers when touching the screen as these will be difficult to remove

without damaging the screen. You can fit a screen protector to your microK (not supplied, but available from local suppliers) to protect the 6.4” screen.

The touch screen can be cleaned with a damp (not wet) cloth. Use either a proprietary screen cleaner (suitable for PC flat panel displays) or water and a little mild liquid soap on a lint-free cloth to wipe the touch screen. Dry the screen immediately after cleaning with a lint-free cloth. The rest of the microK should not require cleaning as often as the display, and can be cleaned in the same way as the screen. Never use abrasive cleaners (such as ‘cream’ cleaners) on your microK.

6 Making Zero-Power Resistance Measurements

The sense current used to measure the resistance of a PRT (for example, the 1mA used with a 25Ω SPRT) causes a small but significant amount of self heating of the platinum element (generally a few mK). This offset is nominally constant under given conditions and is often ignored since it should affect the thermometer equally during calibration and in use. However, the offset can vary (even when conditions are apparently identical) due to differences in the thermal contact between the thermometer and its environment. This means that the same thermometer may exhibit a slightly different resistance when used in two identical temperature sources or even in the same temperature source after being removed and replaced. This effect is significant in the most accurate thermometry work.

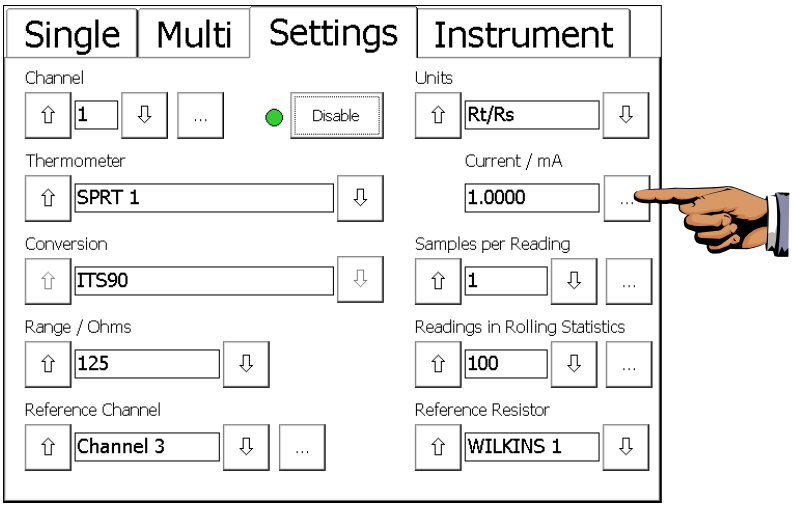
This uncertainty can be eliminated by determining the resistance of the SPRT at zero current (zero power). Whilst the resistance cannot be measured with zero current, it is possible to measure the resistance at 2 different currents and extrapolate back to determine the value at zero current. The most common way to do is this to make a measurement at the normal current and then to increase (or decrease) the current by a factor of $\sqrt{2}$ ($\approx$1.414). This changes the power by a factor of 2 and allows easy determination of the zero-power resistance (by subtracting the change in resistance from the first measurement). Although $\sqrt{2}$ is commonly used (since it makes the calculation easy), any two currents can be used in the extrapolation process.

The microK (in common with other thermometry bridges) supports the ability to vary the sense current in this way in order to support extrapolation back to the zero power resistance. It provides $\times\sqrt{2}$ and $\div\sqrt{2}$ buttons to simplify the scaling of the current. Uniquely, the microK is able to sequence the current and generate a zero-power corrected value and an uncertainty figure for this value without using any external software.

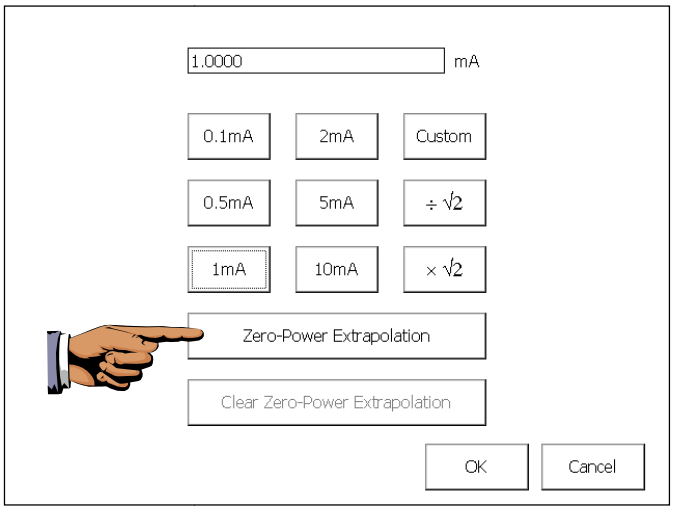
Each zero-power measurement consists of three sets of readings taken at the normal current the alternate current and then the normal current again. The

number of readings taken at each current can be defined as can the settling time allowed for the thermometer's temperature to stabilise after each change in current as follows:

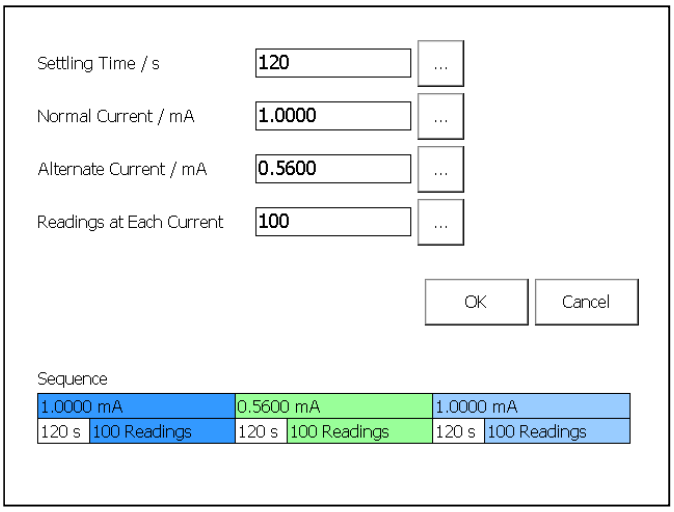
In the *Setting* tab, press the ellipses button by "Current / mA":



When the current window opens, press *Zero-Power Extrapolation*:



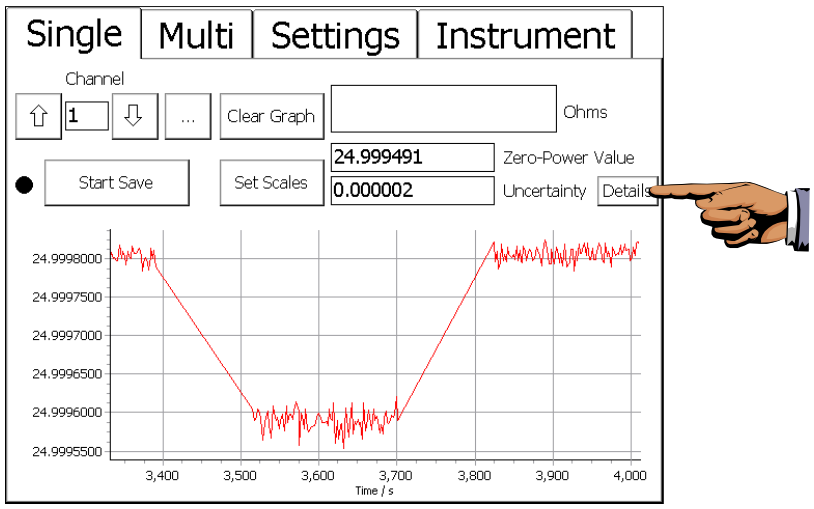
In the current sequence window, use the ellipses buttons to set each parameter:



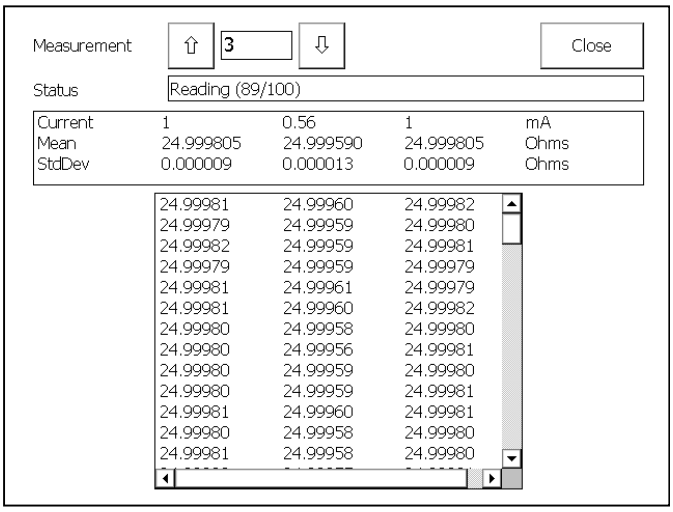
The sequence defined by the parameters is shown at the bottom of the window, in this case it comprises:

1. a 120s settling time
2. 100 readings at 1mA
3. a 120s setting time
4. 100 readings at 0.56mA
5. a 120s settling time
6. 100 readings at 1mA

You can view the status of each measurement sequence and see the results appear by pressing *Details* in the 'Single' of 'Multi' tabs:

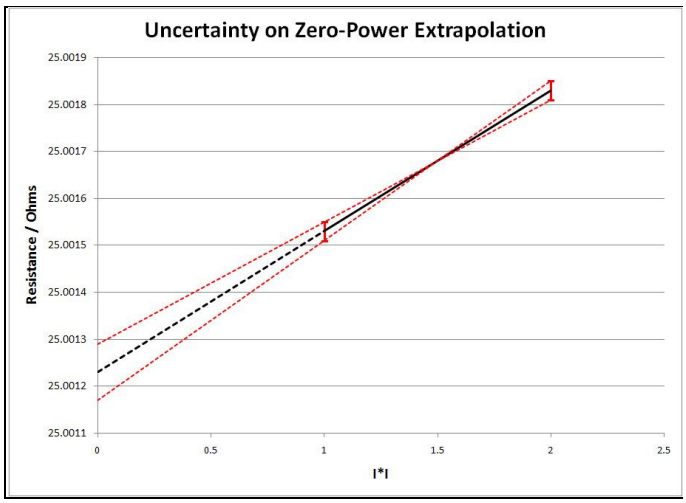


The 'Details' window shows the current status of the measurement and allows you to look back at earlier measurements by using the Up/Down buttons by the 'Measurement' field:



6.1 Zero-Power Uncertainty Calculation

The software calculates the standard deviation for the three data sets in the measurements. These are used to determine the uncertainty of the mean of these data sets and from this the software then calculates the uncertainty of the zero-power extrapolated value:



The effect of self heating is very small and can reasonable be regarded as linear with power. If the actual zero-power resistance is "x" and the measured resistance is "x_n" at current "i_n" then the measurements at the 2 currents will be:

$$x_1 = x + ki_1^2$$
$$x_2 = x + ki_2^2$$

where k is the (unknown) power coefficient.

The extrapolated (zero-power) value can easily be determined by eliminating k from these 2 equations:

$$x = \frac{x_1 i_2^2 - x_2 i_1^2}{i_2^2 - i_1^2}$$

The mean of the results for the first and last (third) set of readings are used for x_1. The mean of the middle (second) set of readings are be used for x_2.

The uncertainty in the zero-power value is determined by:

1. Calculating the uncertainties (the standard deviation of the data set divided by the square root of the data set size) u_1 and u_2 for the two data sets used to calculate x_1 and x_2

2. Calculating the propagation of these uncertainties to the extrapolated value x by differentiating the above equation for x with respect to x_1 or x_2

3. Combining the effect of these two uncertainties u_1 and u_2 using the root sum of squares

The uncertainty in the extrapolated value x arising from the noise (defined by the standard deviation calculations) associated with the data sets is:

$$u'_1 = \frac{dx}{dx_1} u_1 = \frac{i_2^2}{i_2^2 - i_1^2} u_1$$

$$u'_2 = \frac{dx}{dx_2} u_2 = \frac{-i_1^2}{i_2^2 - i_1^2} u_2$$

The combined uncertainty (reported by the microK) is therefore:

$$u = \left| \frac{1}{i_2^2 - i_1^2} \sqrt{i_2^4 u_1^2 + i_1^4 u_2^2} \right|$$

As we would expect, the above equation predicts that the uncertainty of the extrapolated result increases as i_2 approaches i_1. The equation allows us to investigate the optimum ratio between i_1 and i_2. For a resistance bridge such as the microK, the noise and therefore the uncertainty of measurement will be

inversely proportional to the sense current used. So if we let $i_2 = ki_1$, then $u_2 = u_1/k$. Substituting into our uncertainty equation we get:

$$u = \left| \frac{u_1}{k^2 - 1} \sqrt{k^4 + \frac{1}{k^2}} \right|$$

If we differential this with respect to k and set this equal to zero in order to find a minimum for u we get:

$$2k^6 + 3k^2 - 1 = 0$$

The relevant solution to this equation if k=0.55938. This means that the optimum ratio between the alternate and normal current is not $1/\sqrt{2}$, but 0.56. This applies to all resistance bridges, but just the microK. The improvement in uncertainty in going for $1/\sqrt{2}$ to 0.56 is only 13% because u is fairly insensitive to k for values near to 0.56. For convenience, a ratio of 0.5 is a sensible choice as there is less than a 2% degradation in uncertainty between this and the optimum value.

7 The microK Technology

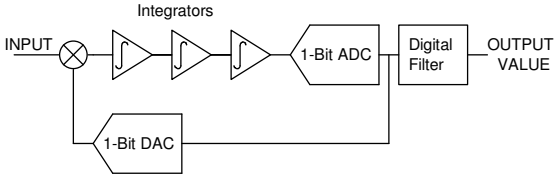
The microK uses a number of new technologies and measurement techniques to achieve performance that was previously only available using AC resistance bridges (for measuring the resistance of PRTs) and separate high-precision digital multi-meters (for measuring the EMF generated by thermocouples).

The concept for the core ADC technology was licensed from NPL (the UK's national standards laboratory) and operates under NPL's "Technology Applied" scheme.

7.1 The ADC

The ADC (Analogue-to-Digital Converter) in a precision instrument is the 'measurement engine'. Its performance is the starting point for achieving low measurement uncertainty. The microK uses a completely new type of ADC, which was designed specifically for this product. It is based on the well established Σ-Δ (sigma-delta) technique but uses multi-bit feedback to achieve performance that is not achievable with conventional Σ-Δ ADCs.

In a conventional Σ-Δ ADC, the analog input signal is subtracted from the output of a 1-bit DAC before being filtered by a series of cascaded integrators. The signal then passes to a 1-bit ADC that drives the DAC and forms a feedback loop

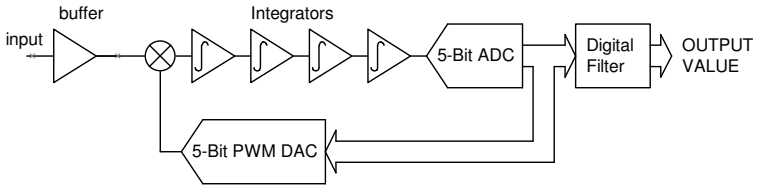


Conventional Σ-Δ ADC

The extremely high gain of the cascaded integrators (at low-frequency) ensures that the input signal is balanced against the output of the DAC so that the average value of the 1-bit data stream from the DAC equals the input signal. A low-pass digital filter is then used to extract the converted value from the 1-bit data stream.

Another way of viewing the operation of a Σ-Δ ADC is to consider what is happening in the frequency domain. The over-sampling used in Σ-Δ converters means that the quantisation noise caused by the 1-bit ADC is spread over a wide bandwidth, whereas the signal we are looking for is unaffected by this over-sampling. The digital filter selects the narrow bandwidth of the required signal. The amount of quantisation noise in this bandwidth is relatively small because the over-sampling spreads the noise power over such a large bandwidth.

The quantisation noise on the converted signal can be reduced by increasing the sampling rate, but it becomes increasingly difficult to maintain performance as the clock rate of the system increases. Another way to reduce the noise would be to use a multi-bit ADC and DAC in the feedback loop. This would not normally be feasible since the DAC would carry the full accuracy burden of the measurement system. However, by using a PWM (Pulse-Width Modulation) DAC, in which the output is a signal of fixed frequency and amplitude but variable pulse width, we turn the problem of producing accurate voltage or current levels into one of accurate timing. Whereas achieving sub-ppm voltage accuracy with a DAC would not be feasible in this sort of product, it is possible to achieve the corresponding timing accuracies.



Multi-Bit Σ-Δ ADC

The timing demands of the PWM DAC are, however, far from trivial. The digital filter has to work at the Σ-Δ ADCs clock rate. In the microK, this digital part of the Σ-Δ ADC is implemented in a fast FPGA, which provides both the digital filter that decimates the DAC output (to extract the converted value) and controls the feedback DAC. The full-scale pulse-width on the PWM DAC is only 10µs, so the <0.1ppm linearity of the microK100 corresponds to a timing accuracy of 1ps, or about the time it takes for the electrical signals in the control system to travel 0.3mm.

It might appear that the reduction in quantisation noise from using multi-bit feedback in a Σ-Δ ADC would be directly proportional to the ADC/DAC resolution. However, the reduced differential gain inherent in the higher resolution DAC greatly improves loop stability too. This allows the use of more orders of integration and higher loop gain giving a disproportionate improvement in quantisation noise. With the 5-bit system used in the microK, the quantisation noise is reduced by a factor of 600 so that the performance of the microK is not limited by the Σ-Δ ADC technique but by the semiconductor devices used in the ADC and the preceding pre-amplifier.

Another benefit of the new ADC is its speed. The implementation used in the microK provides conversions to full accuracy in 100ms. This, together with the use of solid-state switching, allows for a very fast reversal rate, which in turn helps to eliminate the effect of any thermal EMFs and reduce the noise (since the system can operate above the corner frequency of the amplifiers 1/f noise).

7.2 Parallel (Low-Noise) Amplification

With the ADC's low noise contribution, the microK's overall noise performance is determined primarily by the input noise of the amplifier used to sense the small voltage developed across the PRT. This noise is generated by the amplifier's input voltage noise and its input current noise flowing through the input impedance. Typical figures for low noise operational amplifiers (or discrete semiconductors) are around $2nVHz^{-½}$ and $0.2pAHz^{-½}$ respectively. The input noise, U_n (for an input impedance of Z=25Ω) can be calculated by performing an

RMS (Root Mean Square) summation of the noise contributions from the voltage noise (v_n) and current noise (i_n):

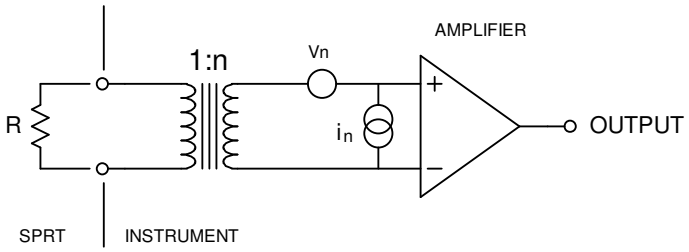
$$U_n = \sqrt{v_n^2 + (i_n Z)^2}$$

$$U_n = \sqrt{(2\times10^{-9})^2 + (0.2\times10^{-12}\times25)^2} = 2.000006 nVHz^{-1/2}$$

The voltage noise clearly dominates the result and the contribution of the current noise is truly negligible.

By using different semiconductor technologies and operating conditions (bias currents) it is possible to reduce voltage noise at the expense of current noise, but for any sensible system, the voltage noise cannot be reduced much below $1nVHz^{-½}$. At this level, the noise is a significant source of uncertainty in typical temperature metrology applications, so that users would need to filter (average) the readings for many minutes in order to achieve their target uncertainty.

The best AC bridge designs use "noise impedance matching" to minimise the noise contribution of the semiconductors used in the amplifier. Since the waveforms in an AC bridge are sinusoidal, a transformer can be used at the input to the amplifier to reduce input noise at the expense of voltage noise:



Noise Impedance Matching in an AC Resistance Bridge

The transformer reduces the voltage noise (referred to the input) by the turns ratio (n). Correspondingly, it increases the current noise by a factor of n. By increasing n it is possible to reduce the voltage noise at the expense of increased current noise. There is clearly an optimum value for n and this occurs when the "noise impedance", which is defined as the ratio of the voltage to current noise

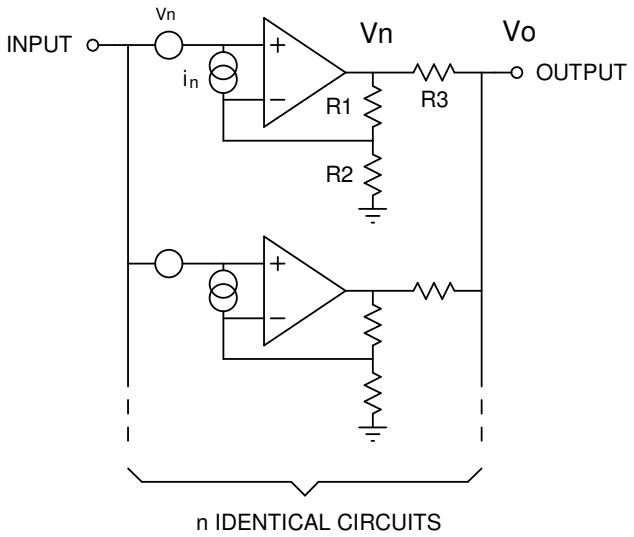
(v_n/i_n), is matched by the transformer to the input impedance, R. This occurs when:

$$n = \sqrt{\frac{v_n / i_n}{R}}$$

In the above example ($v_n = 2nVHz^{-½}$, $i_n = 0.2pAHz^{-½}$, R = 25Ω), this occurs when n = 20. In which case the total noise (RMS summation of contributions) is $u_n = 0.14nVHz^{-½}$. The total noise is therefore reduced by a factor of 14 by the use of the impedance matching transformer.

This noise reduction technique can only be used with an AC resistance bridge (it cannot be used in switched DC bridges or DC current-comparator bridges) and it is for this reason that AC resistance bridges have historically been the instrument of choice for primary standards temperature metrology as well as the most demanding temperature measurement applications.

In developing the microK, we have devised a similar noise reduction technique for use in switched DC systems. The technique involves using a number of amplifiers connected in parallel:



Noise Reduction by Parallel Analogue Processing

The output (v_o) is the mean of the output signals v_x from each amplifier:

$$v_o = \sum_{x=1}^{x=n} \frac{v_x}{n}$$

However, since the input voltage noise is uncorrelated, the noise signals sum statistically (RMS summation). If the voltage noise (v_n) is the same (but uncorrelated) for each amplifier, then the total voltage noise referred to the input is:

$$u_{n1} = \sum_{x=1}^{x=n} \sqrt{\left(\frac{v_n}{n}\right)^2} = \frac{v_n}{\sqrt{n}}$$

The current noise is simply the RMS summation of the current noise (i_n) for each amplifier, giving a noise contribution (in volts) referred to the amplifier input of:

$$u_{n2} = \sum_{x=1}^{x=n} \sqrt{i_n R^2} = \sqrt{n}\, i_n R$$

In a similar way to the noise impedance matching technique we are able to reduce voltage noise at the expense of current noise by using a number of amplifiers connected in parallel (increasing n).

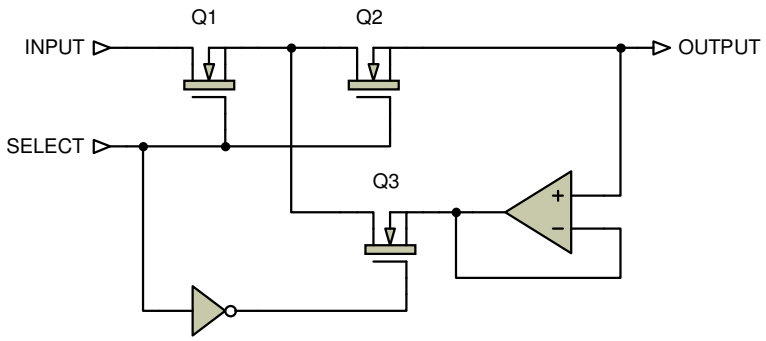
The microK uses a large array of amplifiers in order to reduce the voltage noise to a level that was only previously achievable using AC resistance bridges.

7.3 Buffered Switching

In instruments such as the microK, switching devices are used to route the currents and signals during the measurement process. Ideally, these should have zero on-resistance and infinite off-resistance. The on-state resistance does not normally lead to significant measurement uncertainty, but off-state resistance or leakage is much more critical. In a typical arrangement (a 1mA sense current applied to a PRT) a leakage current of only 100pA would lead to a measurement error of 0.1ppm. Mechanical relays designed for signal switching can provide adequately high off-state resistance such that they contribute negligible measurement uncertainty, but they offer very limited reliability. Semiconductor devices offer very high reliability, but off-state leakage typically leads to significant measurement uncertainty if used to switch signals directly. For this

reason, instruments like the microK have traditionally used mechanical relays in order to achieve performance at the expense of reliability.

The microK uses a buffered switch technology designed to eliminate the effect of the off-resistance of the semiconductors used to switch the signals. Instead of a single switching device, this technique uses two in series that operate together. When the switches are off, the mid-point is connected by a third switching device to a buffered version of the output signal. This means that there is virtually no voltage across the switching device (Q2) when it is off and therefore no significant effect from the off-resistance of that device:

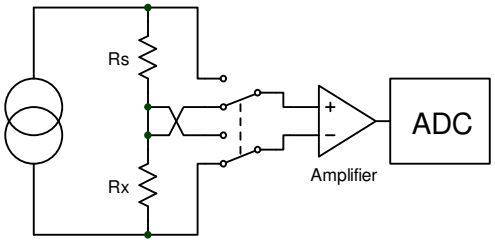


Buffered Switching Arrangement

This technique means that the microK contains no relays or switches (apart from the on/off switch) and therefore offers unrivalled reliability without compromising measurement performance.

7.4 Substitution Topology

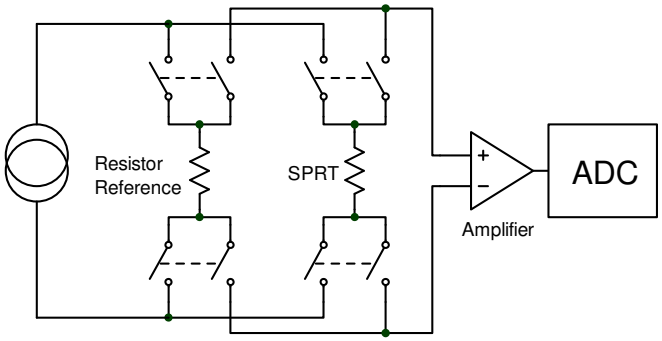
In conventional potentiometric instruments, a common DC current is passed through a thermometer (R_X) and reference resistor (R_S). A voltmeter is switched between reading the voltage across R_X and R_S and the ratio of the two readings is calculated:



Conventional Potentiometric Resistance Measurement

A significant source of error with this measurement topology is the common-mode rejection ratio of the input amplifier. The common-mode signal at the input to the amplifier changes between the two measurements and will lead to an error at the input to the ADC.

In order to eliminate this source of error, the microK uses a substitution topology in which there is a single point of measurement in the system into which the SPRT and Reference Resistor are switched alternately.

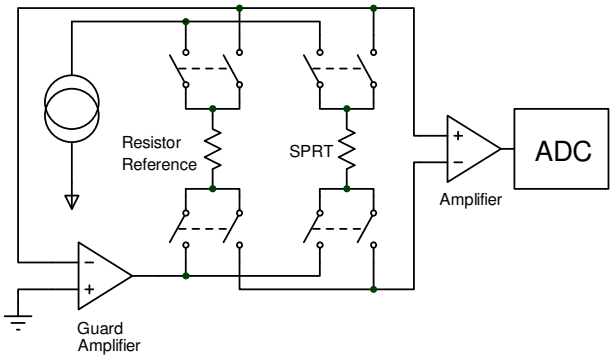


Substitution Measurement Topology

This adds complexity and cost to the design, but ensures that there is no change to the common-mode signal between the measurement of the reference resistor and the thermometer. This approach would normally, however, increase the demands on the current source. In the conventional topology, the current is common to both the reference resistor and the thermometer. In the substitution topology, the voltage at the output of the current source changes between the measurement on the SPRT and the Reference Resistor and the current source

must accommodate this change without any significant change to the sense current.

The current source in the microK has a very high output impedance, such that the sense current will not change significantly between the measurement of the reference resistor and the thermometer. In addition, the whole measurement system is actively guarded so that both the voltage at the output of the current source and the common-mode voltage across the device being measured do not change.



Guarded Measurement System

The Guard Amplifier senses the potential at the 'top' of the measurement system and drives the opposite end in order to maintain it at ground potential. In this way, both the current source and Amplifier see no significant change in voltage/common-mode signal between the measurements of the Reference Resistor and the SPRT.

7.5 Minimising Thermal EMFs

Thermal EMFs (EMFs generated as a result of junctions between dissimilar metals at different temperatures) are a potential source of error when working at this precision. These can largely be eliminated when measuring resistance thermometers by reversing the current and averaging the measurements (the offsets in the two measurements cancel each other out when the readings are averaged together). However, this technique cannot be used when measuring temperature with thermocouples, so the thermal EMFs need to be eliminated at source. For this reason, we used tellurium-copper (gold plated) as the connector

contact material, since this combines good mechanical properties with extremely low thermal EMFs against the copper terminations of a thermocouple.

In order to eliminate thermal EMFs from the measurement system (already small), the input connections are reversed immediately behind the input terminals. Measurements made with and without the reversal are then averaged together to eliminate the thermal EMFs. The limitation is then the thermal EMFs generated by the devices used to implement this reversal.

7.6 Solid-State Switching

One of the most common sources of failure in instruments of this complexity is the contacts in switches, relays, connectors and potentiometers. For this reason, the microK was designed to have no switches (apart from the on/off switch), mechanical relays or potentiometers. The switches normally used for the operator interface have been replaced with a combination of an industrial grade touch-screen over a full-colour VGA LCD, making the instrument both reliable and easy to use The internal connectors are limited to five ribbon cables (with gold plated contacts) for signal interconnections plus a small number of connectors for the AC power and internal DC supply.

Conventional instruments of this type use mechanical relays for some or all of the signal routing. The microK uses only solid-state switching. The thermal EMFs from the metal-silicon junctions in solid-state switching devices are potentially higher than for mechanical relays under the same temperature gradient. However, the very small size of the die within the semiconductor devices means that there would be little opportunity for thermal gradients, giving them a strong advantage over their mechanical counterparts. In practice the thermal EMFs from solid-state switching are significantly less than even the best mechanical relays. As a result, the microK achieves voltage offsets significantly less that 250nV.

7.7 Inherent Stability

The current reversals used to eliminate thermal EMFs from resistance measurements together with true 4-wire resistance measurement have the effect of ensuring an intrinsically stable zero with time and temperature. The voltage at

the amplifier input when measuring a short-circuit will be the same whichever current direction is used. The process of averaging the measurements therefore yields zero (with uncertainty determined by the system noise).

In a similar way, the substitution topology means that the measurement system is also inherently stable at unity ratio since the voltages measured for a reference resistor and thermometer of the same value will be identical. There is, after all, no difference between these two measurements apart from the fact that they are taken at slight different times. The system noise will again determine the uncertainty of this unity ratio measurement.

7.8 Eliminating Self-Heating Effects

Although the sense currents used with SPRTs are small, they can still generate self-heating 'errors' of several mK. The most accurate SPRTs typically have very lightly supported elements so the self-heating effect is ironically worst in those SPRTs designed for the most accurate measurements.

The microK includes individual "keep-warm" current sources for each of the three input channels. These replace the sense current when a channel is not being measured and ensure that the power dissipated in an SPRT remains constant.

The most accurate measurements with an SPRT involve measuring its resistance at two sense currents and then extrapolating back to the zero-power value. The microK's user interface provides a simple feature to allow the sense current to be scaled by a factor of $\sqrt{2}$ (a factor of 2 in power) to make this technique easy for the user to implement (see section 3.6). The microK can be configured to change the current between two values and extrapolate back to determine a zero power value automatically (see section 6).

8 Calibration

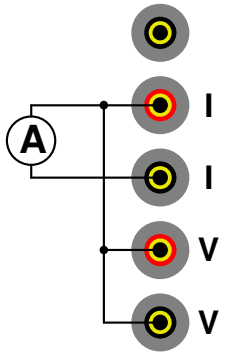
The ADC and measurement topology used in the microK are inherently very stable with both time and temperature. The stability of the microK is primarily determined by its internal standards (a zener reference for voltage and bulk metal foil resistors for resistance). We have used the best available components for these internal standards; a Linear Technology precision zener reference of the type used for voltage transfer standards in electrical metrology and Vishay hermetically sealed bulk metal foil resistors. To keep your microK operating within its performance specification, it should be recalibrated annually. Please contact Isothermal technology to arrange this calibration.

8.1 Checking Calibration

The calibration can be checked by measuring known standards with the microK. The calibration should be performed in a temperature controlled environment between 19°C and 25°C. The microK should be powered up and left to stabilise in the calibration environment for at least 4 hours before checking or adjusting its calibration.

8.1.1 Checking the Master Current Source

The microK current source has 3 ranges (0-0.1mA, 0-1mA and 0-10mA). Check these by connecting a calibrated ammeter (or DMM) across the current terminals of channel 1 and connecting both the sense inputs to the red current terminal:



Checking the master current source involves connecting a PC to your microK (using a null-modem RS232 cable) and sending commands to it from Hyperterminal (part of the standard Windows operating system installation) or

another terminal emulator. For further details of how to connect a PC to your microK see section 9.

Once you have established communication with your microK, type in the following commands and check that the measured current is within the given limits:

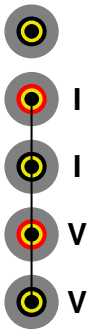
command	current limits
TEST:CURR 0.1	0.0996 to 0.1004 mA
TEST:CURR 1	0.996 to 1.004 mA
TEST:CURR 10	9.96 to 10.04 mA
TEST:CURR -0.1	-0.0996 to -0.1004 mA
TEST:CURR -1	-0.996 to -1.004 mA
TEST:CURR -10	-9.96 to -10.04 mA

8.1.2 Resistance Measurements

The current reversal used by the microK to eliminate the effect of thermal EMFs means that it has an inherently stable zero for resistance measurement. The zero ohms test does not form part of the calibrations process but is used to confirm correct operation of the measurement system. It only needs to be checked on one channel.

8.1.2.1 Zero Ohms Check

Start by applying a four terminal short-circuit to channel 1. This involves shorting out the voltage sense terminals (marked “V”) and the current terminals (market “I”) and then making a single connection between these two set of terminals. The objective is to ensure that none of the sense current passes along the wire between the voltage sense terminals. This can easily be achieved using a single piece of un-insulated wire:



4-Terminal Short-Circuit

Configure the microK to measure a Default PRT at 1mA against the internal 100Ω reference on the 125Ω range on channel 1 (other channels disabled). Set the units to Ohms and use 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Single* tab and clear the statistic. After the microK has collected at least 100 readings (shown as *Mean of last…* in the *Single* tab, check that the *Mean* is less that 0.000004 (4µΩ i.e. 0.032ppm of the 125Ω range) and that the standard deviation (S.D.) is less than 0.00001.

8.1.2.2 400 Ω Internal Reference Resistor

Connect a stable external resistance standard with a nominal value of 100Ω to channel 1. Ideally, this should be a DC or AC/DC resistance reference standard with a recent (traceable) calibration certificate maintained at a constant temperature in an oil bath. Configure the microK to measure a Default PRT at 1mA against the internal 400Ω reference on the 500Ω range on channel 1 (other channels disabled). Set the units to Ratio (Rt/Rs) and use 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Single* tab and clear the statistics. After the microK has collected at least 100 readings (shown as *Mean of last…* in the *Single* tab, check that the *Mean* agrees with the expected value within ±1ppm of value (half of the 10-year specification limit) and that the standard deviation (*S.D.*) is less than 0.000000100.

8.1.2.3 100 Ω Internal Reference Resistor

Repeat the procedure for checking the 400Ω internal reference (see section 8.1.2.2), but configure the microK to measure a Default PRT at 1mA against the internal 100Ω reference using the 125Ω range on channel 1. The *Mean* should agree with the expected value within ±1ppm of value with the standard deviation (*S.D.*) being less than 0.000000200.

8.1.2.4 25 Ω Internal Reference Resistor

Repeat the procedure for checking the 400Ω internal reference (see section 8.1.2.2), but configure the microK to measure a Default PRT at 1mA against the internal 25Ω reference using the 125Ω range on channel 1. The *Mean* should agree with the expected value within ±1ppm of value with the standard deviation (*S.D.*) being less than 0.000002000.

8.1.3 Voltage Measurements

The automatic input reversal of used by the microK when measuring voltage provides good zero stability. However, small differences between the thermal EMFs generated by the devices used to make these reversals on each channel mean that the zero offset needs to be checked for each channel. Once the zero offsets have been checked/adjusted, it is only necessary to check the span on one channel since this part of the measurement system is common to all the channels.

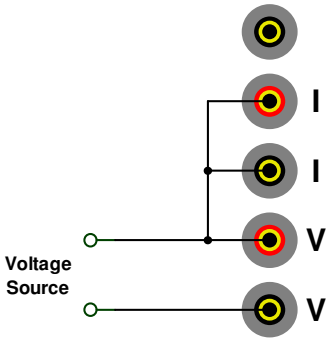
8.1.3.1 Zero Voltage Offsets

Short out the 4 measurement terminals on all 3 channels using a piece of un-insulated copper wire for each channel:

Configure the microK to measure a Default Thermocouple with units set to Volts (all 3 chanels). Use 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Multi* tab and clear the statistics for all 3 channels. After the microK has collected at least 100 readings (shown as *Mean of last…* in the *Multi* tab, check that the *Mean* for each channels is less than 0.00000025 (0.25µV) and that the standard deviation (*S.D.*) does not exceed 0.00000002 (0.02µV).

8.1.3.2 Voltage Span Check

Connect a stable, low noise voltage source with a nominal value of 50mV to channel 1 of the microK using low thermal EMF wire and connectors (copper or an alloy such as tellurium–copper that has a high copper content and low thermal EMF to pure copper. Brass connectors must NOT be used):



Configure the microK to measure a Default Thermocouple with units set to Volts. Use 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Single* tab and clear the statistics. After the microK has collected at least 100 readings (shown as *Mean of last…* in the *Single* tab, check

that the *Mean* value agrees with the applied voltage to within 0.00000025V (0.25µV) and that the standard deviation (*S.D.*) does not exceed 0.00000002V (0.02µV).

Repeat the procedure with the voltage source set to -50mV.

8.2 Adjusting Calibration

This section describes the procedures for adjusting the internal reference standards and the input offset voltages. These can be performed by the user or a third party calibration provider, subject to the availability of the standards specified below. Isothermal Technology additionally checks the temperature coefficient of the zener reference and the linearity of the microK against an RBC (resistance bridge calibration) with an uncertainty of 0.01ppm. We therefore recommend that you return your microK to Isothermal Technology or one of its appointed service centres annually for a comprehensive instrument calibration.

There are no potentiometers inside the microK to adjust, calibration is implemented in software so can be performed without removing the cover from your microK. Calibration is adjusted via the RS232 interface on the rear of the microK. Connect the microK to a PC (using a 9-pin null-modem RS232 cable) and establish an RS232 connection with it using Hyperterminal at 9,600 Baud (for further details of how to connect a PC to your microK see section 9.1). Confirm that the RS232 link is working by typing in *IDN? (terminate this and all commands shown in this section by pressing the carriage return or enter key). The microK will respond with a string in the form:

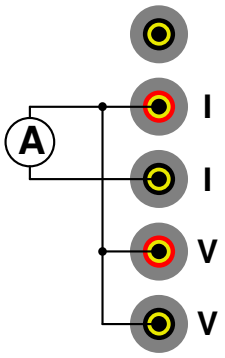
Isothermal Technology, microK 100,09-P119,firmware version 1.14

The calibration of your microK is password protected. Unlocked the calibration to allow calibration adjustment using the command CAL:UNL *password*, where *password* is the calibration system password (NOT necessarily the same as the password used in the touch screen operator interface. The password is initially set to “1234” but should be changed for security reasons (see section 11.6.35). You can now use the SCPI commands (see section 11.6) detailed below to adjust the microK’s calibration.

8.2.1 Calibrate Master Current Source

The microK's current source has 3 ranges (0-0.1mA, 0-1mA and 0-10mA). These share a common reference and the tolerance between the ranges is sufficiently small that it is only necessary to calibrate the 1mA range in order to achieve the full performance specification. The current is controlled by a DAC so adjustment is made in software by scaling the DAC value as required.

Connect a calibrated ammeter (or DMM) across the current terminals of channel 1 and connect both the sense inputs to the red current terminal:



Send the command TEST:CURR 1 to your microK from Hyperterminal (this forces the microK to source 1mA on channel 1). Measure the current and then type in the command CAL:CURR *current* , where *current* is the measured value. Now type in TEST:CURR 1 again to update the current source. The ammeter should now read 1mA ± 0.0003mA.

Check the other current ranges by typing in the following commands and checking that the current is within the given limits:

command	**current limits**
TEST:CURR 0.1	0.09975 to 0.10025 mA
TEST:CURR 10	9.975 to 10.025 mA
TEST:CURR -0.1	-0.09975 to -0.10025 mA
TEST:CURR -1	-0.9975 to -1.0025 mA
TEST:CURR -10	-9.975 to -10.025 mA

8.2.1.1 Calibrating the 400 Ω Internal Reference Resistor

Connect a stable external resistance standard with a nominal value of 100Ω to channel 1. Ideally, this should be a DC or AC/DC resistance reference standard with a recent (traceable) calibration certificate maintained at a constant temperature in an oil bath. Configure the microK to measure a Default PRT at 1mA against the internal 400Ω reference on the 500Ω range with channel 1 (other channels disabled). Set the units to ratio (Rt/Rs) with 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Single* tab and clear the statistics. After the microK has collected at least 100 readings (shown as Mean of last… in the *Single* tab, record the *Mean* value and check that the standard deviation (S.D.) is less than 0.000000100. Calculate the value of the internal resistor from:

$$R400 = \frac{exernal\ reference}{ratio}$$

Adjust the value assigned to the internal 400Ω reference resistors by typing in the command:

CAL:REF205 *R400*

The value entered can be read back using CAL:REF205?. Check the new value assigned to the internal 400Ω reference resistor (see section 8.1.2.2).

8.2.1.2 Calibrating the 100 Ω Internal Reference Resistor

Repeat the procedure for calibrating the 400Ω internal reference (see section 8.2.1.1), but configure the microK to measure a Default PRT at 1mA against the internal 100Ω reference on the 125Ω range with channel 1 (the standard deviation of the measurement should be less than 0.000000200). The command to adjust the value assigned to the 100Ω internal reference is:

CAL:REF204 *R100*

Where *R100* is the value calculated for the 100Ω internal reference.

8.2.1.3 Calibrating the 25 Ω Internal Reference Resistor

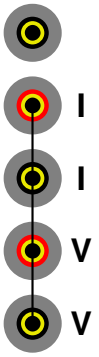
Repeat the procedure for calibrating the 400Ω internal reference (see section 8.2.1.1), but configure the microK to measure a Default PRT at 1mA against the internal 25Ω reference on the 125Ω range with channel 1 (the standard deviation of the measurement should be less than 0.000002000). The command to adjust the value assigned to the 25Ω internal reference is:

CAL:REF203 *R25*

Where *R25* is the value calculated for the 25Ω internal reference.

8.2.2 Calibrating Voltage Zeros

Short out the 4 measurement terminals on all 3 channels using a piece of un-insulated copper wire for each channel:



Type in the following commands to remove the zero/offset correction for all three channels:

CAL:OFFS1 0
CAL:OFFS2 0
CAL:OFFS3 0

Configure the microK to measure a Default Thermocouple with units set to Volts on all 3 channels. Use 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Multi* tab and clear the statistics for all 3 channels. After the microK has collected at least 100 readings (shown as Mean of last… in the *Multi* tab, record the *Mean* for each channel and check that the standard deviation (S.D.) does not exceed 0.00000002 (0.02µV).

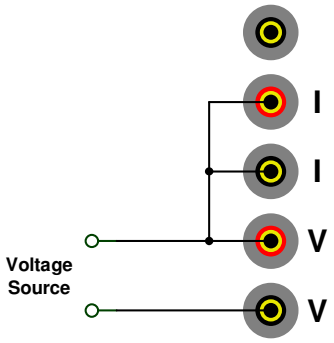
Now adjust the zero offsets using the commands:

CAL:OFFS1 *offset1*
CAL:OFFS2 *offset2*
CAL:OFFS3 *offset3*

Where *offsetX* is the zero offset measured for channel X. The value entered for each channel can be read back using CAL:OFFS*X*? (for channel *X*). Re-check the zero offsets for all three channels (see section 8.1.3.1).

8.2.3 Calibrating Voltage Span

Connect a stable, low noise voltage source with a nominal value of 50mV to channel 1 of the microK using low thermal EMF wire and connectors (copper or an alloy such as tellurium–copper that has a high copper content and low thermal EMF to pure copper. Brass connectors must NOT be used):



Configure the microK to measure a Default Thermocouple with units set to Volts. Use 1 sample per reading and 100 readings in the rolling statistics (see section 3.6). Select the *Single* tab and clear the statistics. After the microK has collected at least 100 readings (shown as Mean of last… in the *Single* tab, record the *Mean* value and check that the standard deviation (S.D.) does not exceed 0.00000002V (0.02µV).

Calculate the require gain from: $$gain = \frac{actual\ value}{measured\ value}$$

Now apply the new gain by typing the command:

CAL:GAIN POS,*gain*

The value entered can be read back using CAL:GAIN? POS

Repeat the procedure with the voltage source set to -50mV. Apply the new negative polarity gain by typing in the command:

CAL:GAIN NEG,*gain*

The value entered can be read back using CAL:GAIN? NEG

9 RS232 Interface

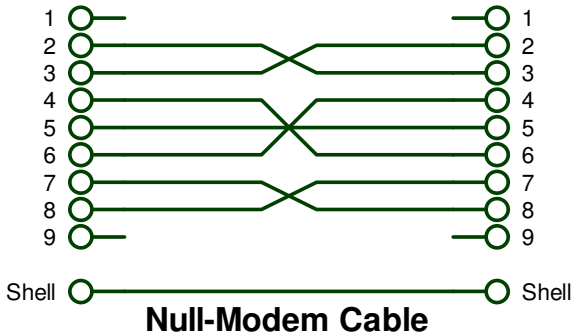
The microK is equipped with an RS232 interface. This can be used to control the microK and perform calibration and diagnostic functions. The command set uses the SCPI (Standard Commands for Programmable Instruments) protocol (see section 11 for details).

9.1 Establishing an RS232 Connection

The RS232 connector is located on the rear of your microK (see section 1.4). The connector is a 9-way (male) D-type configured as a standard DTE device:

Pin	Name	Function
1	CD	carrier detect (not connected)
2	RD	receive data
3	TD	transmit data
4	DTR	data terminal ready (fixed high)
5	SG	signal ground
6	DSR	data set ready (not connected)
7	RTS	request to send
8	CTS	clear to send
9	-	not used (not connected)
Shell	FG	frame ground (screen)

Connect your microK to a PC using a standard null-modem cable:



Null-Modem Cable

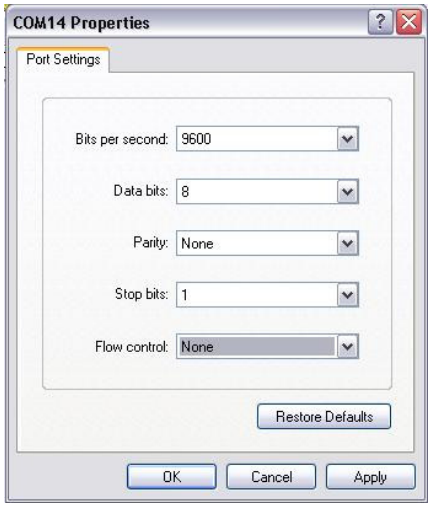
The format for the RS232 interface is as follows:

Baud Rate	9,600
Start Bits	1
Stop Bits	1
Parity Bit	none

The microK has a 254-byte circular receive buffer. If the buffer becomes full, it de-asserts RTS (connected to CTS on your PC through the null-modem cable) to prevent further data being sent. If the PC continues to send data this will be ignored (lost) until the microK has had time to make space in the buffer by processing commands. The microK does not use its CTS to control data it transmits.

You can use Hyperterminal (or another terminal emulator) to communicate with the microK via the RS232 connection. Hyperterminal is part of the standard Windows installation, usually located in the Accessories|Communications folder. If you have installed a minimum (laptop) or custom configuration (without this component) for your Windows operating system, you may need to install Hyperterminal from your original Windows media.

Start Hyperterminal to setup a new connection. Type in a name for the connection (such as microK) and select an icon. In the next window, select the PC's COM port to which you have connected your microK from the *Connect using* drop-down list and click OK. In the next window, enter the data format for the microK's RS232 interface:



Click OK to open a Hyperterminal session with the microK. Now save (using File|Save As) the Hyperterminal connection so that in future you only have to click on this icon to open an RS232 connection with your microK.

Type *IDN? into Hyperterminal (terminate the command by pressing the carriage return or Enter keys), the microK should then respond with a string in the form:

Isothermal Technology, microK 100,09-P110,firmware version 1.16

This confirms that you have successfully established an RS232 connection with your microK.

10 GPIB Interface

The microK is equipped with an IEEE-488 GPIB (General Purpose Interface Bus) port. This can be used to control the microK and perform calibration and diagnostic functions. The command set uses the SCPI (Standard Commands for Programmable Instruments) protocol (see section 11 for details).

The GPIB connector is located on the rear of your microK (see section 1.4). The connector is the standard IEEE-488 connector (24-way) :

Pin	Name	Function	Pin	Name	Function
1	DIO1	Data Input/Output bit	13	DIO5	Data Input/Output bit
2	DIO2	Data Input/Output bit	14	DIO6	Data Input/Output bit
3	DIO3	Data Input/Output bit	15	DIO7	Data Input/Output bit
4	DIO4	Data Input/Output bit	16	DIO8	Data Input/Output bit
5	#EOI	End or Identify	17	#REN	Remote Enable
6	#DAV	Data Valid	18	GND	Ground (paired with #DAV)
7	NRFD	Not Ready for Data	19	GND	Ground (paired with NRFD)
8	NDAC	Not Data Accepted	20	GND	Ground (paired with NDAC)
9	#IFC	Interface Clear	21	GND	Ground (paired with #IFC)
10	#SRQ	Service Request	22	GND	Ground (paired with #SRQ)
11	#ATN	Attention	23	GND	Ground (paired with #ATN)
12	GND	Shield	24	GND	Logic Ground
Shell	-	Frame Ground (cable screen)			

Unlike the RS232 interface (which is full duplex) the GPIB is inherently half-duplex (data can only be transferred between the microK and the GPIB Controller in one direction at any given time, this direction being determined by the controller). If a response is expected from the microK, the GPIB Controller must address the microK as a Talker in order that it can transmit this information. The microK will try to send information on the GPIB for 2s, after which time it will abandon attempts to respond and revert to being a Listener in order to received further commands on the GPIB. This 2s window will start as soon as the microK is ready to respond. There will be a delay from receiving the command to attempting to respond depending on the command (requesting data involves a short delay but requesting a measurement may take up to 2s) and whether the microK is busy processing other commands (if measurements are being requested via the front panel operator interface or via the RS232 interface).

The microK has a 254-byte receive buffer. If the command exceeds this length it will be truncated.

10.1 GPIB Address

The microK behaves as a GPIB Peripheral and can have an address in the range 1 to 30 (inclusive). The factory default address is 10, but this can be changed using SCPI commands (see section 11.6.35) sent on the GPIB or RS232 interface, or through the operator interface (see section 3.7.7)

10.2 Establishing a GPIB Connection

Connect your microK to a GPIB Controller using a standard (straight through) GPIB cable. Send *IDN? to the GPIB address of the microK (see section 10.1) terminated with a Line Feed (see section 11.1 for acceptable terminators), the microK should then respond with a string in the form:

Isothermal Technology, microK 100,09-P110,firmware version 1.16

This confirms that you have successfully established a GPIB connection with your microK.

11 SCPI Command Set

The command format and protocol used by the microK is based on the SCPI (Standard Commands for Programmable Instruments) standard. This was developed to provide a consistent command language for all types of programmable instruments. The objective was to reduce the development time required by users of these instruments by providing a consistent programming environment through the use of defined messages, instrument responses and data formats. Further information on SCPI can be obtained from the SCPI Consortium (http://www.scpiconsortium.org).

11.1 Command Terminators

SCPI commands are ASCII (American Standard Code for Information Interchange) character strings. If sent to the microK's RS232 interface, these should be terminated with a Carriage Return character (ASCII character 13). Responses from the microK on the RS232 interface are always terminated by a Carriage Return character.

If commands are sent to the microK's GPIB port, they can be terminated by a Line Feed character (ASCII 10), Carriage Return character (ASCII 13), EOI condition (by pulling the #EOI line low during the last character of the ASCII string) or any combination of these. Responses from the microK on the GPIB interface are always terminated by a Line Feed character (the microK does not assert EOI at the end of a response).

11.2 SCPI Command Structure

Commands are arranged in a hierarchical tree, similar to directory trees used in personal computers. SCPI uses a defined notation to represent the command tree structure. Each node in the tree structure is a command keyword with keywords being separated by colons (:). To simplify the description of the SCPI commands, the notation represents levels in the tree using horizontal indentations with the root node being the left most column. For example, the microK includes the following command structure:

```
SENSe
        :FUNCTION
        :CHANNEL
        :FREsistance
                :REFerence
                :REFerence?
                :RANGe
                :RANGe?
READ?
CALibrate
        :CURRent
        :OFFSet
        :OFFSet?
```

A valid command is formed by following the tree structure from a root node until a node is reached with no further nodes below it, for example in the above command tree we may use:

```
SENSe:FRESistance:REFerence
```

Keywords can be shortened to the first four letters (or 3 if the last letter is a vowel). To indicate this, the notation uses upper-case to indicate required letters and lower-case to indicate optional letters (NB: all commands are case-insensitive). For example, valid forms of the above command include:

```
Sense:Fresistance:Reference
SENS:FRES:REF
Sense:fresistance:REF
```

To shorten the commands, default (optional) keywords are enclosed in square brackets and may be omitted. For example, in the case of the command:

```
MEASure[:SCALar]:VOLTage:[DC]?
```

Valid forms of this command include:

```
MEAS:VOLT?
MEASURE:SCALAR:VOLTAGE:DC?
```

11.3 SCPI Numeric Suffices

In order to support multiple input channels, commands can include numeric suffices. These are represented by a hash (#) in the command notation, for example:

MEASure:VOLTage:<channel#>?

In addition to the 3 input channels on the front panel (which are assigned the suffices 1, 2 and 3) the internal reference resistors are specified using numeric suffices as follows:

channel#	Internal reference resistor
203	25 Ω
204	100 Ω
205	400 Ω

In order to measure the voltage on channel 3, the command used would be:

MEAS:VOLT3?

11.4 Parameters

If a command requires parameter(s), these follow the command and are separated from it by a space. If more than one parameter is required, each parameter is separated by a comma (,). For example, the command to measure a four-terminal resistance on channel 1 against a reference resistor on channel 2 using the 100 ohm range and a sense current of 1mA would be:

MEAS:FRES1:REF2? 100,1

11.5 Units

Numeric parameters may optionally include units. The standard multiplying prefixes may also be used to indicate decimal multiples or fractions. For example, the following are all equivalent.

CURRENT 0.001A
CURRENT 1ma
CURRENT 1000UA
CURRENT 1

The following prefixes are available:

prefix	*name*	*factor*
N or n	nano	10^{-9}
U or u	micro	10^{-6}
M or m	milli	10^{-3}
K or k	kilo	10^{+3}
MA or ma	mega	10^{+6}

11.6 Making Measurements using SCPI Commands

The microK's measurement system is controlled by a microprocessor connected to the rear panel RS232 interface and a GPIB port. The measurement system can be controlled by SCPI commands from either of these. The firmware makes no distinction between commands received on the RS232 interface and those from the GPIB and will process these in the order in which they are detected. If a response is expected, it will always be sent on the interface (RS232 or GPIB) on which the corresponding command was sent.

There is no direct interference between measurements made using the front panel operator interface and measurements requested using SCPI commands. However, measurements take some time to complete so there may be a delay in responses to SCPI commands if measurements are being made via the front panel operator interface. To avoid unnecessary delays to responses to SCPI commands, you can stop all measurements requested via the front panel operator interface. The easiest way to do this is to restart the microK and then not press *Resume* in the opening window. The main application that provides the user interface will then not start and no measurements will be requested.

11.6.1 Measuring Resistance using SCPI Commands

In order to measure the resistance of a PRT, you need to:

- set the microK to measure resistance
- set the sense current
- select the measurement range
- select the measurement channel
- select the reference channel
- make the measurement

If you want to measure a 25.5Ω SPRT up to a maximum resistance of 30Ω against the internal 100Ω reference, the maximum resistance that the measurement system sees is 100Ω. To make this measurement using a 1mA sense current, you can use the following command sequence:

```
SENS:FUNC  FRES
CURR  1
SENS:FRES:RANG 100,1
```

```
SENS:CHAN  1
SENS:FRES:REF  204
READ?
```

The microK will then report the measured resistance, for example "2.5250637862E001".

The following command performs the same measurement:

```
MEAS:FRES1:REF204?  100,1
```

11.6.2 Measuring Voltage using SCPI Commands

In order to measure the voltage from a thermocouple, you need to:

- set the microK to measure voltage
- select the measurement channel
- make the measurement

If you want to measure the voltage from a thermocouple, you can use the following command sequence:

```
SENS:FUNC   VOLT
SENS:CHAN  1
READ?
```

The microK will then report the measured voltage, for example "1.12999999E-007".

The following command performs the same measurement:

```
MEAS:VOLT1?
```

11.6.3 Measuring Temperature using SCPI Commands

In order to measure temperature, you need to make one of the base unit measurements (resistance or ratio for PRTs, resistance for thermistors or voltage for thermocouples) and then convert this into a temperature using a conversion algorithm (for example ITS-90 for an SPRT). The data for the conversion temperature algorithms is stored in a database accessed from the operator interface. It would be very difficult to make this information available through

SCPI commands so it is not possible to request a measurement in temperature units using SCPI commands. However, it is possible to set up measurement(s) using the operator interface and then to access the results using SCPI commands. To do this, simply setup your microK to make the required measurement from the front panel (see section 2.2 for an example of how to do this) and then when the microK is running and making the required measurement send the command:

READ<channel>?

Where <channel> is the number of the channel from which you require the measurement. The microK will then echo the measurement the next time a results is available for that channel. It will report the value and units, for example: "+9.87654321E+010,C".

Where units	= X	(for ratio)
	= R	(for ohms)
	= K	(for Kelvin)
	= C	(for °C)
	= F	(for °F)

If the microK detects that the requested channel is not enabled, it will report "not enabled". The READ#? Command can be cancelled (in order to allow measurements from another channel to be requested) by send the command:

ABORt

11.6.4 SCPI Commands

The microK supports the following commands:

```
*IDN?
*RST
SENSe
        :FUNCtion[:ON]              <function>
        :FUNCtion[:ON]?
        :CHANnel                    <channel>
        :CHANnel?
        :FRESistance
                :REFerence          <reference channel>
                :REFerence?
                :RANGe[:UPPer]      <resistance range>,<current>
                :RANGe[:UPPer]?
        :RATio
                :REFerence          < denominator channel>
                :REFerence?
                :RANGe[:UPPer]      <resistance range>,<current>
                :RANGe[:UPPer]?
INITiate[:IMMediate][:ALL]
FETCh[:SCALar]?
READ[:SCALar]?
MEASure[:SCALar]
        :VOLTage[:DC]<channel#>?
        :FRESistance<channel#>
                :REFerence<reference#>?     <resistance range>,<current>
        :RATio<channel#>
                :REFerence#?                <resistance range>,<current>
[:SOURce]:CURRent                           <current>
TEST
        :CURRent                    <current>
CALibrate
        :CURRent                    <actual current>
        :REFerence<reference#>      <actual resistance>
        :REFerence<reference#>?
        :OFFSet<channel#>           <offset>
        :OFFSet<channel#>?
        :GAIN                       <polarity>,<adjustment>
        :GAIN?                      <polarity>
        :GAIN:RESet
        :GPIB:ADDRess               <gpib address>
        :GPIB:ADDRess?
        :PASSword                   <old password,< password>,< password>
        :UNLock                     <password>
        :LOCK
```

A detailed description of each command follows:

11.6.5 Command: *IDN?

Format: *IDN?

Reports information on the microK in 4 comma separated fields:

- manufacturer
- model
- serial number
- firmware version

Example: for a microK 100 with serial number 09-P119 ITL261067 using firmware version 1.14, the microK responds to *IDN? with:

Isothermal Technology,microK 100,09-P119 ITL261067,firmware version 1.14

11.6.6 Command: *RST

Format: *RST

Performs a reset (equivalent to a power-on reset) of the measurement system firmware.

11.6.7 Command: SENSe:FUNCtion

Format: SENSe:FUNCtion <*function*>

Selects the measurement function. The parameter <*function*> must be one of the following valid SCPI parameters:

- VOLTage[:DC]
- FRESistance
- RATio

Example: to set the microK to measure ratio, use: SENS:FUNC RAT

11.6.8 Command: SENSe:FUNCtion?

Format: SENSe:FUNCtion?

Reports the current measurement function.

Example: a microK set to measure voltage will respond to SENS:FUNC? with "VOLTAGE".

11.6.9 Command: SENSe:CHANnel

Format: SENSe:CHANnel <*channel*>

Selects the channel for the next measurement. The channel is not actually selected until a measurement is started using either the INITiate or READ? commands.

Example: to select channel 2 for the next measurement, use: SENS:CHAN 2

11.6.10 Command: SENSe:CHANnel?

Format: SENSe:CHANnel?

Reports the channel selected for the next measurement.

Example: a microK set to measure channel 1 on the next measurement will respond to SENS:CHAN? with: "1".

11.6.11 Command: SENSe:FRESistance:REFerence

Format: SENSe:FRESistance:REFerence <*reference channel*>

Selects the reference channel for the next resistance measurement made. The channel is not actually selected until a measurement is started using either the INITiate or READ? commands. The channel numbers used for the internal reference resistors are:

- Channel 203 = 25 Ω
- Channel 204 = 100 Ω
- Channel 205 = 400Ω

Example: to select channel 2 as the reference channel for the next resistance measurement, use: SENS:FRES:REF 2

11.6.12 Command: SENSe:FRESistance:REFerence?

Format: SENSe:FRESistance:REFerence?

Reports the channel selected as the reference channel for the next resistance measurement.

Example: a microK set to use channel 2 as the reference in the next resistance measurement will respond to the command SENS:FRES:REF? with: “2”.

11.6.13 Command: SENSe:FRESistance:RANGe

Format: SENSe:FRESistance:RANGe[:UPPer] <*resistance range*>,<*current*>

Sets the range for the next resistance measurement. The range is determined by the voltage range of the measurement system (0.125 or 0.5V) and depends on the sense current used. The *current* parameter is the current you intend to use in the measurement, this may not be the same as the present value of sense current that is set with the CURRent command. The 2 resistance ranges available with the microK are:

- *resistance range = 0.125V / current*
- *resistance range = 0.5V / current*

The resistance range specified should be the higher of the maximum PRT resistance and reference resistor since the measurement system has to measure the signal across both to determine the resistance of the device under test.

Example: to set the microK to measure a PRT that has a maximum resistance of 130Ω (using a 100Ω reference resistor) with a 1mA sense current, use: SENS:FRES:RANG 130,1. This will set the microK to the 0.5V range.

11.6.14 Command: SENSe:FRESistance:RANGe?

Format: SENSe:FRESistance:RANGe[:UPPer]?

Reports the range for the next resistance measurement at the present sense current (set using the CURRent command). The current used to calculate the range may be different from that specified when the range was set using the SENSe:FRESistance:RANGe command. The reported range is the actual range for the measurement system at the present sense current.

Example: a microK that has had its resistance range set using the command shown in section 11.6.13 but has its sense current set to 10mA would respond to the command: SENS:FRES:RANG? with: “50.000000”.

11.6.15 Command: SENSe:RATio:REFerence

Format: SENSe:RATio:REFerence <*reference channel*>

Selects the reference channel for the next resistance ratio measurement made. The channel is not actually selected until a measurement is started using either the INITiate or READ? commands. The channel numbers used for the internal reference resistors are:

- Channel 203 = 25 Ω
- Channel 204 = 100 Ω
- Channel 205 = 400Ω

Example: to select channel 2 as the reference channel for the next resistance ratio measurement, use: SENS:RAT:REF 2

11.6.16 Command: SENSe:RATio:REFerence?

Format: SENSe:RATio:REFerence?

Reports the channel selected as the reference channel for the next resistance ratio measurement.

Example: a microK set to use channel 2 as the reference in the next resistance ratio measurement will respond to the command SENS:RAT:REF? with: “2”.

11.6.17 Command: SENSe:RATio:RANGe

Format: SENSe:RATio:RANGe[:UPPer] <*resistance range*>,<*current*>

Sets the range for the next resistance ratio measurement. The range is determined by the voltage range of the measurement system (0.125 or 0.5V) and depends on the sense current used. The *current* parameter is the current you intend to use in the measurement, this may not be the same as the present value of sense current that is set with the CURRent command. The 2 resistance ranges available with the microK are:

- *resistance range = 0.125V / current*
- *resistance range = 0.5V / current*

The resistance range specified should be the higher of the maximum PRT resistance and reference resistor since the measurement system has to measure the signal across both to determine their ratio.

Example: to set the microK to measure the resistance ratio of a PRT that has a maximum resistance of 130Ω (with a 100Ω reference resistor) with a 1mA sense current, use: SENS:RAT:RANG 130,1. This will set the microK to the 0.5V range.

11.6.18 Command: SENSe:RATio:RANGe?

Format: SENSe:RATio:RANGe[:UPPer]?

Reports the range for the next resistance ratio measurement at the present sense current (set using the CURRent command). The current used to calculate the range may be different from that specified when the range was set using the SENSe:RATio:RANGe command. The reported range is the actual range for the measurement system at the present sense current.

Example: a microK that has had its resistance ratio range set using the command shown in section 11.6.17 but has its sense current set to 10mA would respond to the command: SENS:RAT:RANG? with: “50.000000”.

11.6.19 Command: INITiate

Format: INITiate[:IMMediate][:ALL]

Initiates a measurement using the conditions defined by previous SENSe commands. The measurement is made immediately, but not reported.

Example: to initiate a voltage measurement that has been defined with SENSe commands (such as SENS:CHAN 1 and SENS:FUNC volt) use: INIT

11.6.20 Command: FETCh?

Format: FETCh[:SCALar]?

Reports the result of the last measurement made.

Example: a microK that has made a measurement on a short circuit connected to channel 1 using the commands shown in the example in section 11.6.19 will respond to FETC? with something similar to : “1.70000000E-008”.

11.6.21 Command: READ?

Format: READ[:SCALar]?

Initiates and reports a measurement using the conditions defined by previous SENSe commands. This is equivalent to INIT followed by FETCh?

Example: a microK that is connected to a short circuit on channel 1 and has been configured to make a voltage measurement using SENSe commands (such as SENS:CHAN 1, SENS:FUNC volt and SENS:VOLT:RANG 0.1) will respond to READ? with something similar to : “1.70000000E-008”.

11.6.22 Command: MEASure:VOLTage?

Format: MEASure[:SCALar]:VOLTage[:DC]<channel#>?

Initiates and reports a voltage measurement on <channel#> using the voltage range specified (note that there is no gap between the command and the channel number as this command makes use of the numeric suffices feature of SCPI described in section 11.3). This command is equivalent to SENS:FUNC volt, SENS:CHAN *<channel>* and READ?

Example: to initiate a voltage measurement on channel 3 use: MEAS:VOLT3?

11.6.23 Command: MEASure:FRES:REF?

Format: MEASure[:SCALar]:FRESistance<channel#>:REFerence<reference#>?

<resistance range>,<current>

Initiates and reports a resistance measurement on <channel#> against a reference on channel <reference#> using <resistance range> with sense <current> (note that there is no gap between the command and the channel numbers as this command makes use of the numeric suffices feature of SCPI described in section 11.3). This command is equivalent to SENS:FUNC fres, SENS:FRES:REF

<reference#>, SENS:FRES:*RANG <resistance range>,<current>*, SENS:CHAN *<channel>* and READ?

Example: to set the microK to measure a PRT on channel 1 that has a maximum resistance of 130Ω using a 100Ω reference resistor on channel 2 with a 1mA sense current, use: MEAS:FRES1:REF2? 130,1

11.6.24 Command: MEASure:RAT:REF?

Format: MEASure[:SCALar]:RATio<channel#>:REFerence<reference#>?

<resistance range>,<current>

Initiates and reports a resistance ratio measurement on <channel#> against a reference on channel <reference#> using <resistance range> with sense <current> (note that there is no gap between the command and the channel numbers as this command makes use of the numeric suffices feature of SCPI described in section 11.3). This command is equivalent SENS:FUNC rat, SENS:RAT:REF *<reference#>*, SENS:RAT:*RANG <resistance range>,<current>*, SENS:CHAN *<channel>* and READ?

Example: to set the microK to measure the resistance ratio of a PRT on channel 1 that has a maximum resistance of 130Ω against a 100Ω reference resistor on channel 2 with a 1mA sense current, use: MEAS:RAT1:REF2? 130,1

11.6.25 Command: CURRent

Format: [SOURce]:CURRent *<current>*

Set the sense current for the next resistance or ratio measurement to *<current>*. The current is not changed until a measurement is started using either the INITiate or READ? commands.

Example: to set the sense current for the next resistance measurement to 2mA use: CURR 2

11.6.26 Command: TEST:CURRent

Format: TEST:CURRent *<current>*

Immediately sets the sense current on channel 1 to <*current*>.

Example: to set the sense current on channel 1 to 5mA use: TEST:CURR 5

11.6.27 Command: CALibrate:CURRent

Format: CALibrate:CURRent <*actual current*>

This command is used after using the TEST:CURR 1 command and measuring the current from channel 1 (see section 8.2.1). It uses the actual current entered to adjust the master current source to the correct current. The adjustment is only applied if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38).

Example: the current from channel 1 after using the command TEST:CURR 1 was measured as 1.00123. To adjust the master current source correctly use: CAL:CURR 1.00123

11.6.28 Command: CALibrate:REFerence

Format: CALibrate:REFerence<reference#> <*actual resistance*>

Used to calibrate the internal <*reference#*> standard by assigning a new <*actual resistance*> to it. The adjustment is only applied if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38).

The channel numbers (numeric suffices) used for the internal resistor are given in section 11.3. The calibrated value is stored as a floating point number and will therefore be subject to some rounding (less than 0.12ppm of value)

Example: if the value of the internal 100Ω reference has been measured as 100.00123, the new value can be assigned to it using: CAL:REF204 100.00123

11.6.29 Command: CALibrate:REFerence?

Format: CALibrate:REFerence<reference#>?

Used to report the calibrated value of the internal <reference#> resistor (used by the microK to calculate resistance).

Example: a microK with an internal 25Ω reference having a calibrated value of 25.01234 will respond to CAL:REF203 with “25.01234”

11.6.30 Command: CALibrate:OFFSet

Format: CALibrate:OFFSet<channel#> <offset>

Adjusts the voltage offset for <*channel#*> used when making voltage measurements. The offset range is ±2µV, attempts to apply an offset greater than this will be ignored. The adjustment is only applied if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38). The offset is stored as a floating point number and will therefore be subject to some rounding (less than 0.12ppm of value)

Example: to subtract an offset of 0.123µV from voltages measured on channel 3 use: CAL:OFFS3 0.123

11.6.31 Command: CALibrate:OFFSet?

Format: CALibrate:OFFSet<channel#>?

Reports the offset subtracted from voltage measurements on <*channel#*>

Example: a microK that has been calibrated to have a 0.123µV offset subtracted from voltage measurement on channel 2 will respond to CAL:OFFS2? with “1.23E-07”.

11.6.32 Command: CALibrate:GAIN

Format: CALibrate:GAIN <*polarity*>,<*adjustment*>

Adjusts the measurement system’s voltage gain for <polarity> by the factor <adjustment>. The parameter <polarity> must be either POSitive or NEGative. The adjustment is only applied if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38).

The gain adjustment is stored as a floating point number and will therefore be subject to some rounding (less than 0.12ppm of value)

Example: for a microK that has been found to have a voltage gain for positive readings that is low by a factor of 1.000123 (see section 8.2.3), the gain can be corrected using: CAL:GAIN POS,1.000123

11.6.33 Command: CALibrate:GAIN?

Format: CALibrate:GAIN? <*polarity*>

Reports the total calibration adjustment applied to the measurement system's voltage gain. The parameter <polarity> must be either POSitive or NEGative.

Example: a microK that has had a number of gain adjustments causing a total ratio adjustment of 1.000123 for positive readings will respond to CAL:GAIN? POS with "1.000123"

11.6.34 Command: CALibrate:GAIN:RESet

Format: CALibrate:GAIN:RESet <*polarity*>

Resets the gain adjustment for the specified <polarity> to 1. The parameter <polarity> must be either POSitive or NEGative. The gain reset is only implements if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38).

Example: to remove all calibration adjustment (set adjustment to 1) for positive voltages use: CAL:GAIN:RES POS

11.6.35 Command: CALibrate:GPIB:ADDRess

Format: CALibrate:GPIB:ADDRess <*gpib address*>

Sets the GPIB address to <gpib address>. The address must be in the range 0-30 (inclusive). The change is only made if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38).

Example: to set the GPIB address to 21 use: CAL:GPIB:ADDR 21

11.6.36 Command: CALibrate:GPIB:ADDRess?

Format: CALibrate:GPIB:ADDRess?

Example: a microK with GPIB address 10 will respond to CAL:GPIB:ADDR? with “10”

Reports the GPIB address.

11.6.37 Command: CALibrate:PASSword

Format: CALibrate:PASSword <*old password*>,<*password*>,<*password*>

Changes the password used to lock (protect) the calibration of the microK’s measurement system. This is initially set to “1234”, but should be changed before using the microK for any critical or traceable measurement or calibration work. The new password must be at least 4 characters in length and must be typed in identically twice in order to effect the change. The change is only applied if calibration has already been unlocked using the CALibrate:UNLock command (see section 11.6.38).

Example: to change the password from 1234 to ABCD use: CAL:PASS 1234,ABCD,ABCD

11.6.38 Command: CALibrate:UNLock

Format: CALibrate:UNLock <*password*>

Unlocks the microK to allow calibration adjustment. The microK always powers up in the locked state. Calibration can be re-locked by re-powering the microK or using CAL:LOCK (see section 11.6.39).

Example: to unlock (enable) the calibration adjustment on a microK with the default password (“1234”), use: CAL:UNL 1234

11.6.39 Command: CALibrate:LOCK

Format: CALibrate:LOCK

Locks the microK to prevent calibration adjustment.

Example: to lock the calibration of a microK after adjustment, use: CAL:LOCK

12 Specification

Ranges	Resistance Thermometers:	0Ω to 100k Ω
	Thermocouples:	±125mV
Accuracy – PRTs	µK100:	0.1ppm maximum over whole range for SPRT with $R_0 \geq 2.5\Omega$ (equivalent to 0.025mK at 0°C, or 0.1mK over full range).
		0.25ppm maximum over whole range for SPRT with $R_0=0.25\Omega$
	µK200:	0.2ppm maximum over whole range for SPRT with $R_0 \geq 2.5\Omega$ (equivalent to 0.05mK at 0°C, or 0.2mK over full range).
		0.5ppm maximum over whole range for SPRT with $R_0=0.25\Omega$
Accuracy – Thermocouples	Voltage uncertainty:	250nV (between 0 and 20mV)
	equivalent to 0.01°C for Gold-Platinum thermocouple at 1000°C	
Resolution	Resistance:	0.001ppm of range
	Voltage:	1nV
Stability	Resistance (excluding resistance standard):	0 (note1)
	Voltage:	3ppm/year
Measurement Time	2s	
Temperature Conversions	PRTs:	ITS-90, Callendar-van Dusen
	Thermocouples:	IEC584-1 1995 (B,E,J,K,N,R,S,T), L and gold-platinum
	Thermistors:	Steinhart-Hart
Sensor Current	0-10mA in 3 ranges:	
	0.1mA	±0.4% of value, ±70nA, resolution 28nA
	1mA	±0.4% of value, ±0.7µA, resolution 280nA

	10mA ±0.4% of value, ±7µA, resolution 2.8µA
Keep-Warm Current	0-10mA ±0.4% of value, ±7µA, resolution 2.8µA
Cable Length	<30m (maximum 10Ω per core or 10nF shunt capacitance)
Internal Standard Resistors	25, 100 and 400 Ω: tolerance = ±0.1%, TCR = ±0.05ppm/°C stability = ±2ppm over 10 years
Input Connectors	"Cable Pod" connectors for: 4mm plugs, spades or bare wires Contact material: gold plated tellurium copper
Interfaces	RS232 (9,600 baud) Ethernet (IEEE 802.3/803.3u: 100Base-TX / 10Base-T) USB (1.1) – host
Display	163mm / 6.4" VGA (640 x 480) colour TFT LCD
Operating Conditions	15-30°C / 50-85°F (for full specification) 5-40°C / 40-105°F (operational) 10-80% RH
Power	88 – 264V (RMS), 47-63Hz (Universal) 25W maximum, 1.5A (RMS) maximum
Size	520mm x 166mm x 300mm / 20.5" x 6.6" x 11.9" (W x D x H)
Weight	12.4kg / 27lb

Notes:

1. The microK uses a 'substitution technique' in which the Device-Under-Test and the Reference are successively switched into the same position in the measuring circuit. This means that the stability of resistance ratio measurements is immeasurably small (see section 7.4)

13 Approvals

The microK has been independently verified as complying with the regulatory requirements of the EU and FCC for electromagnetic compatibility and safety (EU only).

13.1 CE Declaration

European Community Electromagnetic Compatibility Directive (89/336)
European Community Low Voltage Directive (93/68)

The microK Precision Thermometry Bridge manufactured by Isothermal Technology Limited of Pine Grove, Southport, Merseyside, PR9 9AG, United Kingdom conforms to the requirements of the European Community Electromagnetic Compatibility Directive (89/336) and of the European Community Low Voltage Directive (93/68).

13.2 FCC Statement

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area may cause harmful interference, in which case the user will be required to correct the interference at his own expense. Changes or modifications to this equipment not expressly approved by Isothermal Technology could degrade EMC performance and void the user's authority to operate the equipment.

13.3 Standards Applied

The following standards have been applied in assessing compatibility with the requirements for CE marking and for FCC compliance:

Conducted Emissions	EN61326:1997 & CFR47:2005
Radiated Emissions	EN61326:1997 & CFR47:2005
Conducted Immunity	EN61326:1997
Radiated Immunity	EN61326:1997
Electrical Fast Transients	EN61326:1997
Electrostatic Discharge	EN61326:1997
Surge	EN61326:1997
Voltage Dips & Interruptions	EN61326:1997
Harmonic Currents	EN61000-3-2:2000
Flicker	EN61000-3-3:1995
Electrical Safety	EN61010-1:2001